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TESTING AND ANALYSIS OF MODIFIED HMMWV FRONT LIFT PROVISIONS

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MECHANICS AND STRUCTURES BRANCH

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ABSTRACT

The U.S. Army Materials Technology Laboratory (MTL) was requested by the Tank and Automotive Command (TACOM) and the Military Traffic Management Command (MTMC) to investigate the performance of the modified front lift provisions on the high mobility, multipurpose, wheeled vehicle (HMMWV). In order to evaluate the front lift provisions, a series of simulated air lift, ultimate pull, and fatigue tests were performed. Each type of test was performed for two different load magnitudes and angles. In addition to the mechanical tests performed, nondestructive testing procedures were utilized to inspect the provisions for imperfections and cracks before and after testing. A finite element analysis (FEA) was also conducted to analyze the hook and the provision bracket for each of the two load configurations.

CONTENTS

INTRODUCTION

To ensure the safety of soldiers during air lift operations, the U.S. Army Materials Technology Laboratory (MTL) conducted an investigation into the structural integrity of the modified front lift provisions on the high mobility, multipurpose, wheeled vehicle (HMMWV). These modifications include an increased hook diameter (from 5/8" to 3/4"), the installation of a gusset plate between the ends of the hook, and a reinforced provision bracket (see Figure 1). Still, with these modifications for increased strength there appears to be some *movement* of the provisions during air lift operations. This movement pertains to the deflection of the front lift provisions inwards toward each other when a HMMWV is air lifted.

In order to evaluate the front provisions while mounted to the vehicle, a series of simulated air lift tests were performed. A HMMWV was fastened to a steel platen so its lift provisions could be loaded by an overhead crane. Fastening the vehicle to the platen allowed loads of 3.2 g to be achieved. This procedure was performed for two different load magnitudes and angles; 9600 lb sling load at 30^{o}, and 11,370 lb sling load at 45^{o}.

Once the simulated air lift tests were completed, the next step was to evaluate the provisions themselves, independent of the vehicle. To do so, two types of tests were performed: the first was the ultimate pull test where a provision was loaded to failure, and the second was a 5000 cycle fatigue test. For both the ultimate pull and fatigue tests, the two load configurations (load magnitudes and angles) from the simulated air lift tests were utilized.

In addition to the mechanical testing, the provisions were examined using two nondestructive testing (NDT) methods, X-ray radiography, and the magnetic particle process. Both methods were used to analyze the provisions for surface cracks and other flaws before and after testing.

Finite element analyses (FEA) were conducted to determine the effects of the two loading configurations on the front provisions.

TEST PROCEDURES

Simulated Air Lift Tests

To simulate the loads experienced during air lift operations, a HMMWV was anchored to a steel platen (see Figure 2) using jack stands, chains, and chain binders. The load was applied to the lift provisions via an overhead crane (see Figure 3). By fixing the vehicle to the platen, the required load of 3.2 times the working load (as required by MIL-STD-209G) on the provisions could be achieved (the working load pertains to the gross weight of a fully loaded HMMWV distributed among the four lift points of the vehicle).

The two load configurations utilized were a 9600 lb sling load (per sling) at a sling angle of 30^{o}, and a more severe configuration was an 11,370 lb sling load (per sling) with a sling angle of 45^{o} (see Figure 4 for load configurations). These load configurations represent a fully loaded HMMWV that is experiencing a 3.2 g loading due to air lift maneuvers. Each configuration possesses a different sling length which varies the angle at which the loads are applied.

For all the air lift simulation tests, the load on each of the front slings was monitored and recorded with the use of in-line load cells and X-Y recorders (see Figure 5). One end of each load cell was connected to a provision while the other end was attached to the sling. The remaining end of the sling was attached to the overhead crane.

Prior to testing, the provisions on the HMMWV were replaced with two modified lift provisions. Once installed, both provisions and part of the HMMWV frame were painted with stress coat. Stress coat is a lacquer-like coating that becomes brittle once it is cured. When the provisions are loaded, the stress coat cracks thus identifying the stressed areas.

One pull using each load configuration was performed. These preliminary test showed where the high stress areas on the provisions and frame were located. These areas were designated as the locations for the installation of strain gages (BLH strain gages were used for all tests). Following these tests, a new set of provisions were strain gaged and installed on the vehicle.

For the next set of simulated air lift tests, data from the strain gages was recorded using the MEGADAC High Speed Data Acquisition System. The system was programmed to store data at a rate of 200 samples per second per strain gage.

The first air lift simulation test used the 9600 lb/30° configuration. The crane loaded the vehicle so that each front provision was subject to a 9600 lb pull. The loading rate for the simulation tests was approximately 2000 lb/sec and the maximum load was sustained for a period of 90 seconds (as required by MIL-STD-209G) before being unloaded.

Upon the completion of the first test, the slings were adjusted for testing the provisions using the 11,370 lb/45° configuration. Again, the crane loaded the vehicle so that each of the front provisions experienced an 11,370 lb pull, also sustained for 90 seconds, then unloaded. Figure 6 shows the load profiles for both load configurations.

Ultimate Pull Tests

To assess the overall strength of the provision, an ultimate pull laboratory test was performed for each load configuration utilizing a new provision for each test (designated provisions A and B). These tests were performed in a 150,000 lb hydraulic tension/compression test machine (see Figure 7).

For these tests, each provision was instrumented with strain gages which were read continuously throughout each test.

The first ultimate pull test performed was the 9600 lb/30° configuration on provision A. Due to the test machine's load path and our desire to fully simulate the manner by which the provision is loaded on the HMMWV, the test fixture was installed at an angle of 5° with respect to horizontal and with a 3.25" offset from the line of loading. The provision was mounted on the fixture at an angle of 18° forward to the line of loading (see Figure 8). These angles and the offset assured that the out-of-plane load was applied at the same angles as those of a provision mounted on a HMMWV.

Once provision A was installed, four loading cycles were performed, the first three cycles to a load of 9600 lb and the fourth cycle to failure.

The second ultimate pull test was the 11,370 lb/45^{O} configuration performed on provision B. For this series of tests, the fixture was installed at an angle of 12^{O} with respect to the horizontal and with an offset of 5" from the line of loading. Again, the provision was installed at an angle of 18^{O} forward to the line of loading. This provision then experienced four loading cycles; three cycles to a load of 11,370 lb, and the fourth cycle to failure.

Fatigue Tests

In order to help determine how well the provisions would perform after repeated air lifts, fatigue tests were conducted on two new (never tested) provisions, one for each configuration; designated provisions C and D. The number of cycles chosen for each test was 5000. This number of cycles was mutually agreed upon by MTMCTEA and the Tank and Automotive Command (TACOM) to exceed the number of times a HMMWV would be air-lifted in its own lifetime. Prior to testing, the provisions were analyzed using the NDT processes mentioned earlier. In addition, they were also strain gaged at the same locations as the provisions used in the ultimate pull tests. The same 150,000 lb test machine used for the ultimate pull tests was also utilized for these tests. The provisions and the fixture were installed in the test machine using the same procedures as those used for the ultimate pull tests.

The first load configuration to be employed was the 11,370 lb/45^{O} load configuration on provision C. The loading scheme was divided into two segments. For cycles one through 50, the load was applied at a rate of 0.2 g/sec (1 g = 2700 lb) up to a maximum load of 11,370 lb, held for a period of 90 seconds then unloaded. The cycle time for each of the first 50 cycles was 132 sec/cycle. Once the maximum load was achieved, the data acquisition system would then take a reading of all the strain gages. For cycles 51 through 5000, the load was applied at the same rate up to the maximum load of 11,370 lb and held for three seconds; in that three seconds, the data acquisition system was signaled to record the strain gage readings, then the provision was unloaded. The time for each cycle was 45 sec/cycle.

The last load configuration was then used to test provision D. For cycles one through 50, the load was applied at a rate of 0.1 g/sec up to a maximum load of 9600 lb, held for a period of 90 seconds and then unloaded. Just as in the previous test, strain gage readings were taken when the maximum load was achieved. The time duration for each cycle was 161 seconds. Then, for cycles 51 through 5000, the loading was applied at the same rate up to the maximum load of 9600 lb and held for three seconds; strain gage readings were taken in that three seconds, then the provision was unloaded. For cycles 51 through 5000, the time for each cycle was 73 seconds.

Finite Element Analysis (FEA)

The analysis of the lift provision was divided into two sections. The first was the analysis of the hook portion of the provision for both load configurations. The second was the analyses of the provision bracket utilizing both configurations.

To analyze the performance of the hook under the 3.2 g loading, a three-dimensional model was developed. The model was constructed of 47 beam elements, each with a cross-sectional radius of 0.375". Boundary conditions applied to the model held the base of the hook as fixed supports (see Figure 9 for hook illustration).

To analyze the remainder of the provision, a three-dimensional model of the provision bracket was created utilizing shell elements. Due to varying thicknesses on the provision, the elements were grouped accordingly so that the correct thickness could be assigned to the corresponding elements. The boundary conditions applied to this model held the nodes fixed at the bolt hole locations. See Figure 10 for a full model illustration.

The loads to be applied to both of these models were broken down into their components and applied at the proper locations for each model. These locations were determined from the provisions used for the lift tests which had already been completed. The chains used during these tests left indentations in the hook for each configuration. These indentations identified the points of loading.

The material properties used for these analyses were determined experimentally. Material property characterization tests were performed to determine Young's modulus, yield stress, and Poisson's ratio of the material. These values were found to be 29.5E6 psi, 83,500 psi, and 0.287, respectively. The data obtained was then converted to true stress strain data for input to the finite element models.

Each model was then used to perform an elastic plastic analysis (utilizing ABAQUS Finite Element Software) for each load configuration.

RESULTS

Simulated Air Lift Tests

Prior to installing the new provisions on the HMMWV for testing, they were inspected using X-ray radiography and the magnetic particle processes. No defects or cracks were found.

The first two pulls (one at each load configuration) with the use of stress coat revealed that the high strain areas were located in the bolt hole areas, the weld area at the intersection of the top flange on the mounting bracket and box beam, and at the base of the hook (see Figure 11). The high strain areas were found to be in the same locations for both loading configurations.

Once these areas were identified, strain gages were bonded at these locations on a new set of lifting provisions prior to further testing (see Figure 12 for strain gage locations). Several strain gages were also mounted to the frame of the vehicle. Due to a limitation on the number of channels that the data acquisition system could read, the high strain area located at the intersection of the top of the flange on the mounting bracket and the box beam was not monitored until the ultimate pull and fatigue tests were conducted. Once strain gaged, these instrumented provisions were then mounted on the vehicle.

The initial simulated air lift test on the instrumented provisions used the 9600 lb/30^{o} configuration. The highest strain sustained by the provision bracket at 9600 lb was -722 microstrain (mstrain) and was recorded by strain gage 4 which is located at one of the bolt hole locations. The peak strain recorded was located on the hook at the top edge of the gusset plate. Gage 1 recorded this strain of -1308 mstrain. Table 1 indicates the peak strains experienced at each strain gage location for a load of 9600 lb.

Table 1. MAXIMUM STRAINS RECORDED AT EACH GAGE UTILIZING THE 9600 LB CONFIGURATION

Gage No.	Maximum Strain (mstrain)	Gage No.	Maximum Strain (mstrain)
1	-1308	12	176
2	617	13	368
3	420	14	81
4	-722	15	109
5	277	16	293
6	40	17	-24
7	-112	18	47
8	-130	19	-171
9	219	20	45
10	541	21	-221
11	45		

Using the same set of instrumented provisions, the second simulated air lift test utilizing the 11,370 lb/45° load configuration was performed. Figure 13 shows a plot of sling load versus time for this test. The high strain area on the bracket was again located and recorded at gage 10. The magnitude of that strain was 1399 mstrain. Figure 14 represents a typical strain versus scan plot generated by the data acquisition software. Gage 1 again recorded the peak strain of -1959 mstrain. Table 2 lists the maximum strains recorded by each strain gage for a load of 11,370 lb.

During the 11,370 lb/45° pull test, it was observed that the lift provisions were rotating elastically inwards toward each other. The provisions transferred the out-of-plane load to the vehicle's main chassis as a moment using the provision as a moment arm. This forces the chassis to rotate about its neutral axes allowing the lift provisions to come into contact with the coils along the sides of the transmission cooler (see Figure 15). These coils were damaged as a result of this movement. It was noted, however, that when the load was removed from the provisions, the provisions returned to their original positions.

Table 2. MAXIMUM STRAINS RECORDED AT EACH GAGE UTILIZING THE 11,370 LB CONFIGURATION

Gage No.	Maximum Strain (mstrain)	Gage No.	Maximum Strain (mstrain)
1	-1959	12	366
2	866	13	983
3	425	14	108
4	-840	15	142
5	635	16	605
6	59	17	37
7	-343	18	146
8	-431	19	-213
9	432	20	106
10	1399	21	-194
11	-67		

Upon the completion of these tests, the lift provisions were removed from the vehicle for NDT inspection. No signs of damage or cracking were discovered.

Ultimate Pull Tests

Pretest NDT inspections showed that provisions A and B had no cracks or flaws prior to testing.

The first set of ultimate pull tests conducted were for the 9600 lb/30^{0} configuration performed on provision A. Provision A was to be cycled three times to a load of 9600 lb and then, on the fourth cycle, pulled to failure. However, due to test machine settings, each of the first three cycles unknowingly reached a load of 12,800 lb. On the fourth cycle, the ultimate load achieved was 29,600 lb. Table 3 contains a summary of cycles, loads, and peak strains achieved during these tests.

Table 3. LOAD CYCLES PERFORMED ON PROVISION A

Cycle	Maximum Load (lb)	Maximum Strain (mstrain)	Gage No.
1	12,800	1879	1
2	12,800	1353	9
3	12,800	1376	9
4	29,600	-4950	3

NOTE: See Figure 16 for stain gage locations.

Table 4 lists the strain value at each gage location for each cycle at a load of 9600 lb. These values were extracted from the data recorded during the three 12,800 lb and the 29,600 lb cycles.

Table 4. STRAINS RECORDED FROM CYCLES 1 THROUGH 4 AT 9600 LB

Gage No.	Cycle 1 (mstrain)	Cycle 2 (mstrain)	Cycle 3 (mstrain)	Cycle 4 (mstrain)
1	1104	*	*	*
2	624	602	661	693
3	-156	-150	-157	-206
4	-164	-153	-179	-216
5	451	457	367	415
6	-133	-83	-57	52
7	-222	-48	*	*
8	*	*	*	*
9	743	602	600	603
10	684	681	702	732
11	165	226	197	196
12	344	348	338	344
13	271	264	265	263
14	625	618	601	567
15	503	486	483	489
16	301	303	310	304

*No response

Upon completion of the first cycle, the gages indicate that some permanent set was present in the hook and had a magnitude of 500 mstrain (or 0.05% strain). The gages on the provision bracket showed that the strains sustained by the bracket were relatively small and fully elastic (the maximum provision bracket strain recorded was 610 mstrain at 9600 lb). For the second and third cycles, the gages indicated that all strains were fully elastic following the first cycle with no further increase in strain.

The final cycle was to pull on the provision until a failure occurred. Rather than risk damaging the test fixture by overloading it, this test was halted upon achieving a maximum load of 29,600 lb. Gages 2 and 3 showed the strains in the hook to be in the order of 5000 mstrain. The maximum strain recorded from the provision bracket was 1952 mstrain (recorded by gage 14, as shown in Figure 16 for location).

Upon removing provision A from the test fixture and inspecting it with the NDE processes, several cracks were found to exist. They were located around one of the bolt holes, at one of the welds connecting the hook to the provision, and at the point at which the hook was loaded. Figure 17 shows these cracks locations.

The second set of ultimate pull tests was conducted on provision B for the 11,370 lb/45^{o} configuration. Provision B was to be cycled three times to 11,370 lb and then to failure; however, due to the machine adjustments mentioned earlier, provision B actually experienced three cycles up to a load of 15,100 lb and an ultimate load of 26,500 lb. The cycles, loads, and peak strains for provision B are summarized in Table 5.

Table 5. LOAD CYCLES PERFORMED ON PROVISION B

Cycle	Maximum Load (lb)	Maximum Strain (mstrain)	Gage No.
1	15,100	3664	6
2	15,100	3594	6
3	15,100	3662	6
4	26,500	12987	1

NOTE: See Figure 16 for strain gage locations.

Table 6 lists the strain at each gage location for cycles one through four at a load of 11,370 lb. These values were extracted from the data recorded during the three 15,100 lb and the 26,500 lb cycles.

Table 6. STRAINS RECORDED FROM CYCLES ONE THROUGH FOUR AT 11,370 LB

Gage No.	Cycle 1 (mstrain)	Cycle 2 (mstrain)	Cycle 3 (mstrain)	Cycle 4 (mstrain)
1	987	1174	1098	1075
2	58	19	72	143
3	-269	-349	-208	201
4	505	416	371	311
5	-866	-53	-60	64
6	2338	1369	1315	1349
7	-1280	-508	-513	-520
8	1016	834	781	720
9	1813	1187	1148	1129
10	72	188	126	301
11	466	451	446	457
12	820	706	710	694
13	223	294	307	287
14	964	905	971	966
15	994	992	916	952
16	413	423	423	406
17	284	110	112	115

Upon completion of the first cycle, the strain gages showed that some permanent set had been induced in the hook at the load of 11,370 lb. The maximum strain in the hook at 11,370 lb was 2338 mstrain and was recorded by gage 6. The maximum set at 11,370 lb was 838 mstrain (or 0.084% strain) and was also recorded by gage 6. The gages on the bracket indicate that strains induced up to the load of 11,370 lb were elastic.

When the final load of 15,100 lb was achieved and the provision was unloaded, the maximum permanent set was again recorded by gage 6 on the hook with a magnitude of 1620 mstrain (or 0.16% strain). The maximum strain experienced by the hook at the load of 15,100 lb was 3665 mstrain and was recorded by gage 6. The maximum strain experienced by the provision bracket was 1375 mstrain and was recorded by gage 15.

The second cycle was fully elastic up to a load of 11,370 lb. Once this load was surpassed, some permanent set was again induced into the hook. Gages 1, 3, 5, 6, and 17 experienced an additional set of 200 mstrain (or 0.02% strain). The remainder of the gages on the hook and provision bracket indicated a fully elastic loading cycle.

During cycle 3, all gages show a fully elastic loading cycle with no further increase in strain except for gage 17. Gage 17, which is located at the point of the applied load, shows an increase of approximately 30 mstrain.

The final cycle was to pull the provision to failure. However, to avoid risking damage to the test fixture, the maximum load achieved was 26,500 lb. Gages 1, 3, 6, and 9 all show that the hook had surpassed the yield strain of the material. In addition, gages 12, 13, 14, and 15 show that the provision bracket had surpassed the yield point of the material.

After completing all four cycles, provision B was removed from the test fixture for inspection. The provision was found to have several cracks at the bolt hole locations and one at the top inside weld of the hook (see Figure 18).

Fatigue Tests

Prior to testing, provisions C and D were inspected for cracks or other defects. Some porosity was found to exist in one of the welds that connects the gusset plate to the hook on provision C.

The first 5000 cycle fatigue test to be performed was conducted on provision C using the 11,370 lb/45^{o} load configuration. Table 7 lists the maximum strains achieved at the end of the 5000 cycles.

Table 7. STRAINS RECORDED FROM THE END OF THE 5000 CYCLE FATIGUE TEST USING THE 11,370 LB CONFIGURATION

Gage No.	Strain (mstrain)	Gage No.	Strain (mstrain)
1	593	9	1512
2	417	10	311
3	-1118	11	451
4	213	12	931
5	-2408	13	300
6	4208	14	1172
7	-860	15	1320
8	386	16	327

NOTE: See Figure 16 for strain gage locations.

From this fatigue test, it was found that the hook yields almost immediately at gage 6. The trend for the gages on the hook shows the permanent set and the peak strain to be increasing as the number of cycles climbs. For example, at cycle 1000, gage 6 has a permanent set of 1599 mstrain and a peak strain of 3837 mstrain. At cycle 5000, the same gage has a permanent set of 1868 mstrain and a peak strain of 4208 mstrain. This peak strain of 4208 mstrain was the maximum recorded during this test. The maximum strain recorded from the gages mounted to the provision bracket was 1320 mstrain, recorded by gage 15. It was also noted that all gages on the provision bracket (refer to Figure 16 to locate gages) experienced some amount of permanent set, with the maximum set occurring at gage 15 with a magnitude of 370 mstrain (or 0.037% strain).

The last fatigue test to be performed was the 9600 lb/30^{o} configuration utilized on provision D. Table 8 lists a summary of the maximum strains recorded at the end of the fatigue test on provision D.

Table 8. STRAINS RECORDED FROM THE END OF THE 5000 CYCLE FATIGUE TEST USING THE 9600 LB CONFIGURATION

Gage No.	Strain (mstrain)	Gage No.	Strain (mstrain)
1	1452	9	285
2	906	10	776
3	-1180	11	218
4	149	12	640
5	-583	13	740
6	761	14	972
7	396	15	788
8	-230	16	326
		17	7817

NOTE: See Figure 16 for strain gage locations.

During this test, gage 17 showed that the hook at that location was experiencing a strain equal to 7817 mstrain with a permanent set of 3800 mstrain. This indicates that this point on the hook easily surpasses the yield criteria for this material. The remaining gages on the hook showed maximum strains of 1452 mstrain or less. The maximum strain experienced by the gages mounted to the provision bracket was 972 mstrain and was recorded by gage 14. The maximum set experienced by these gages was 310 mstrain (or 0.031% strain) which occurred at gage 14. The strain results indicate that there was little increase in strain as the number of cycles climbed.

Following the fatigue tests, provisions C and D were inspected. There were no signs of cracking or any other damage.

Finite Element Analyses (FEA)

The first analysis performed was that of the hook being loaded by the 11,370 lb/45^{o} configuration. The concentrated load was broken into its components and applied at node 14. These load components are listed below (see Figure 19 for illustration).

$$Fx = -7834 \text{ lb}$$

$$Fy = 8044 \text{ lb}$$

$$Fz = 1803 \text{ lb}$$

The results show that yielding occurs at three general locations. Two of the locations are the bases of the hook above the gusset plate and the third is the point on the hook at which it is loaded on the immediate area. The maximum stresses experienced in the yielded areas are summarized in Table 9 below (refer to Figure 19 for element location).

Table 9. MAXIMUM STRESSES EXPERIENCED AT THE THREE YIELDED SECTIONS OF THE HOOK

Element	Maximum Stress (psi)
1	85,267
14	85,002
47	84,629

The maximum stress sustained by the hook in this analysis occurs at element 1 with a magnitude of 85,267 psi. Element 1 is located at the top of the gusset plate on the loaded side of the hook.

The second hook analysis performed used the 9600 lb/30° configuration. The load was again broken into components (listed below) and applied to node 17 (refer to Figure 19 for node location).

$$Fx = -3644 \text{ lb}$$

$$Fy = 8846 \text{ lb}$$

$$Fz = 839 \text{ lb}$$

The results from this analysis show that two areas of the hook yield at a load of 9,600 lb; these areas were first the point of load application and, secondly, the base of the hook above the gusset plate opposite the point of load application (see Figure 20 for yielded areas). In Table 10, the maximum stresses from each yielded area and the elements at which they occurred are summarized. In this analysis, the maximum stress in the hook was located directly at the point of the load application on element 16.

Table 10. ELEMENTS AT WHICH YIELD STRESS IS EXCEEDED AND THEIR MAXIMUM STRESS FOR THE 9600 LB CONFIGURATION

Element	Maximum Stress (psi)
16	84,276
47	84,224

The next analysis performed was the provision bracket being loaded by the 9600 lb/30° configuration. The same load components (Fx, Fy, and Fz) utilized for this configuration in the hook analysis above were applied at the same location on the hook in this provision model. Figure 21 shows the entire provision model including the load component vectors and the fixed node locations simulating the bolt holes.

The results show that the maximum stresses in the bracket occur in the areas of the bolt locations. Figure 22 shows a stress contour plot of the bolt hole areas. The maximum stress experienced by the provision was 86,649 psi at element 117. This element is adjacent to one of the lower bolt nodes on the box beam portion of the provision (see Figure 23) and was the only one to surpass the yield stress in this analysis. Figure 24 illustrates the undeformed mesh with an overlay of the deformed mesh in the front view for this load case.

The last analysis to be performed was that of the provision bracket loaded in the 11,370 lb/45° configuration. The load components previously used in the hook analysis for this configuration were also utilized at the same location on the hook for this analysis.

The results from this analysis show again that the highest stressed areas on the bracket are the bolt node locations. The stresses around the bolt node locations either approached or surpassed the yield stress (83,500 psi) of the material. Table 11 lists the elements that exceeded the yield stress and their corresponding maximum stress.

Table 11. ELEMENTS AT WHICH THE YIELD STRESS IS EXCEEDED AND THEIR MAXIMUM STRESS FOR THE 11,370 LB CONFIGURATION

Element	Maximum Stress (psi)
33	89,677
40	-85,784
77	96,080
86	93,206
117	94,465
124	-92,433
299	94,656
301	86,260
315	-85,062
318	-93,682
355	87,836

Figure 25 shows the stress contours around the bolt nodes for this analysis.

CONCLUSIONS

From the simulated air lift tests, it was found that for the 11,370 lb/45° configuration, the strains sustained by the provisions were much greater than those of the 9600 lb configuration. Maximum strains recorded by the strain gages approached the yield criteria of the material but did not surpass it.

The ultimate pull tests showed that the provisions would perform adequately for the 9600 lb lift configuration but not necessarily for the 11,370 lb. The strains indicate that during the 11,370 lb pull test, the hook did begin to yield.

The fatigue tests proved that for both load configurations, yielding does occur. During the 9600 lb test, yielding was found to occur at the loading point of the hook. During the 11,370 lb test, yielding occurred at the top of the hook next to the loading point. In addition, there was little increase in strain as the number of cycles climbed.

The finite element results reveal that for both load configurations, a certain amount of yielding does occur at various locations. For the 9600 lb configuration the load application point, one of the hook bases, and a bolt hole location experienced yielding. In the 11,370 lb analysis, both bases of the hook and the point of load application experienced stresses above yield. In addition, the immediate areas surrounding five of the 10 bolt nodes surpassed the yield stress of the material.

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The authors would like to express their sincere thanks to Bob Pasternak, Wayne Bethoney, Bill Crenshaw, and Fran Muncey of MTL and Richard Fanco, Craig Finch, and Andrew Spaman of AM General for their assistance in the variety of tests which were successfully conducted. Special thanks to Ray Hackley of MTL for his assistance that made the 3.2 g air lift tests possible.

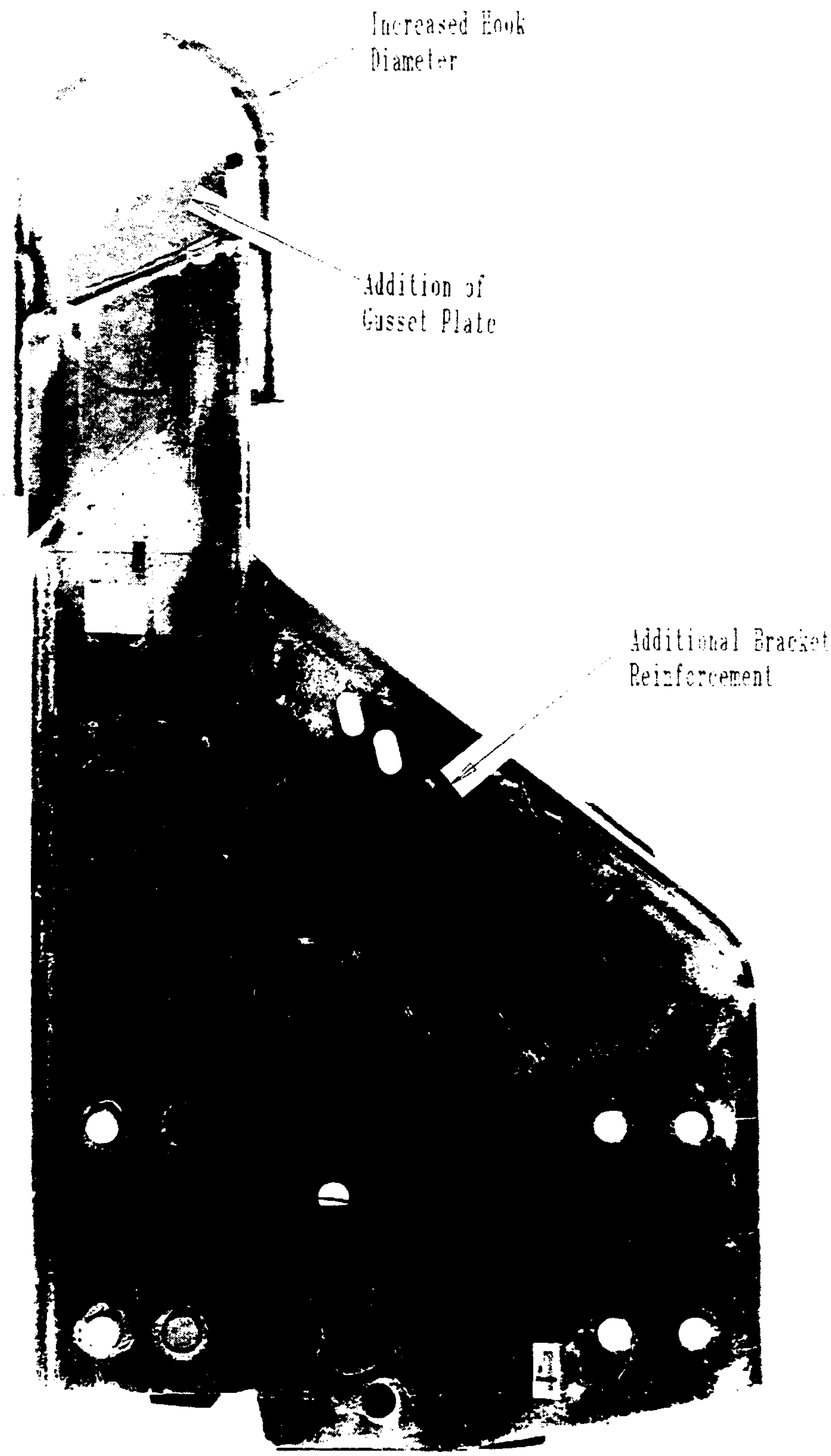

Figure 1. Modifications to old lift provision.

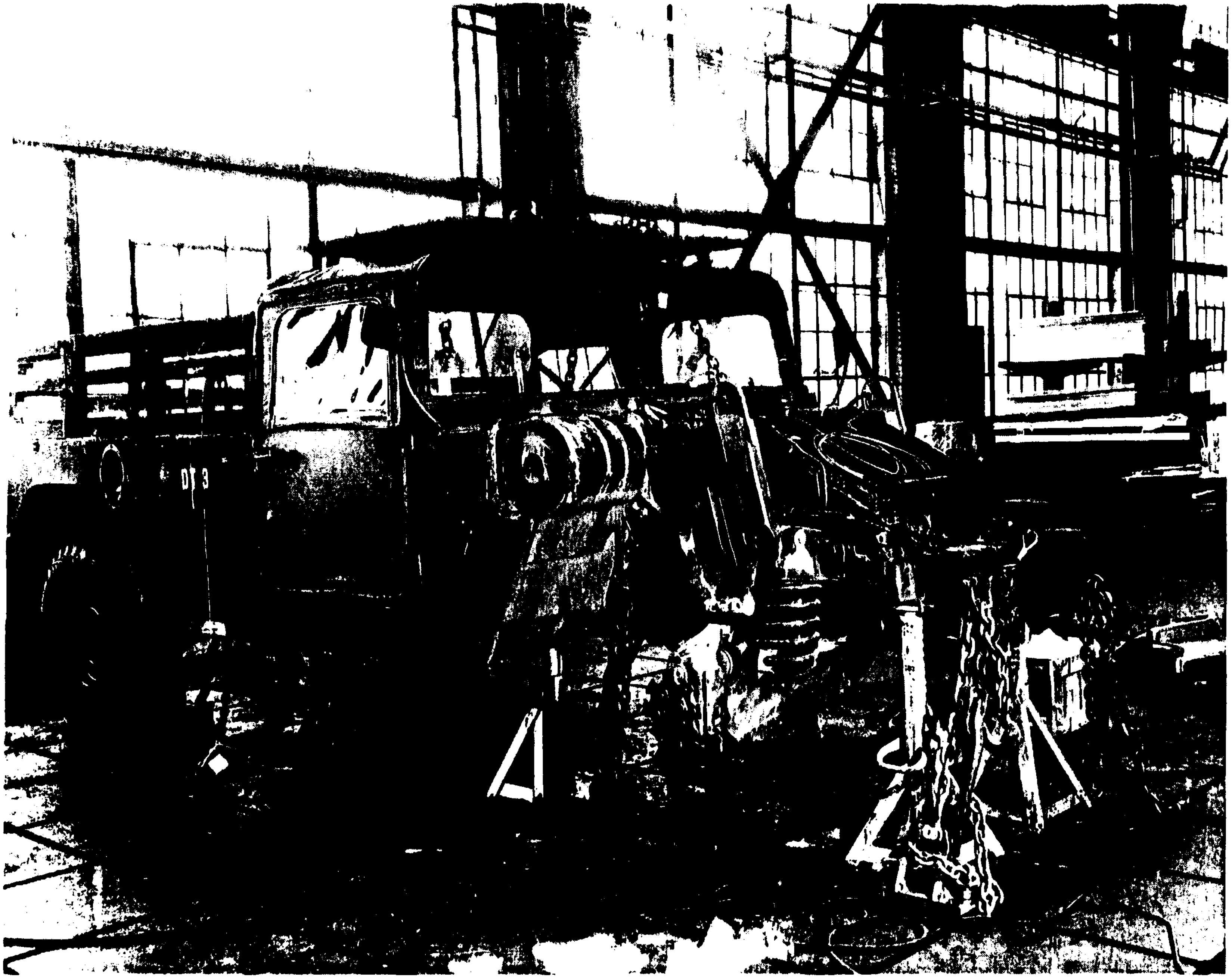

Figure 2. HMMWV fixed to platen.

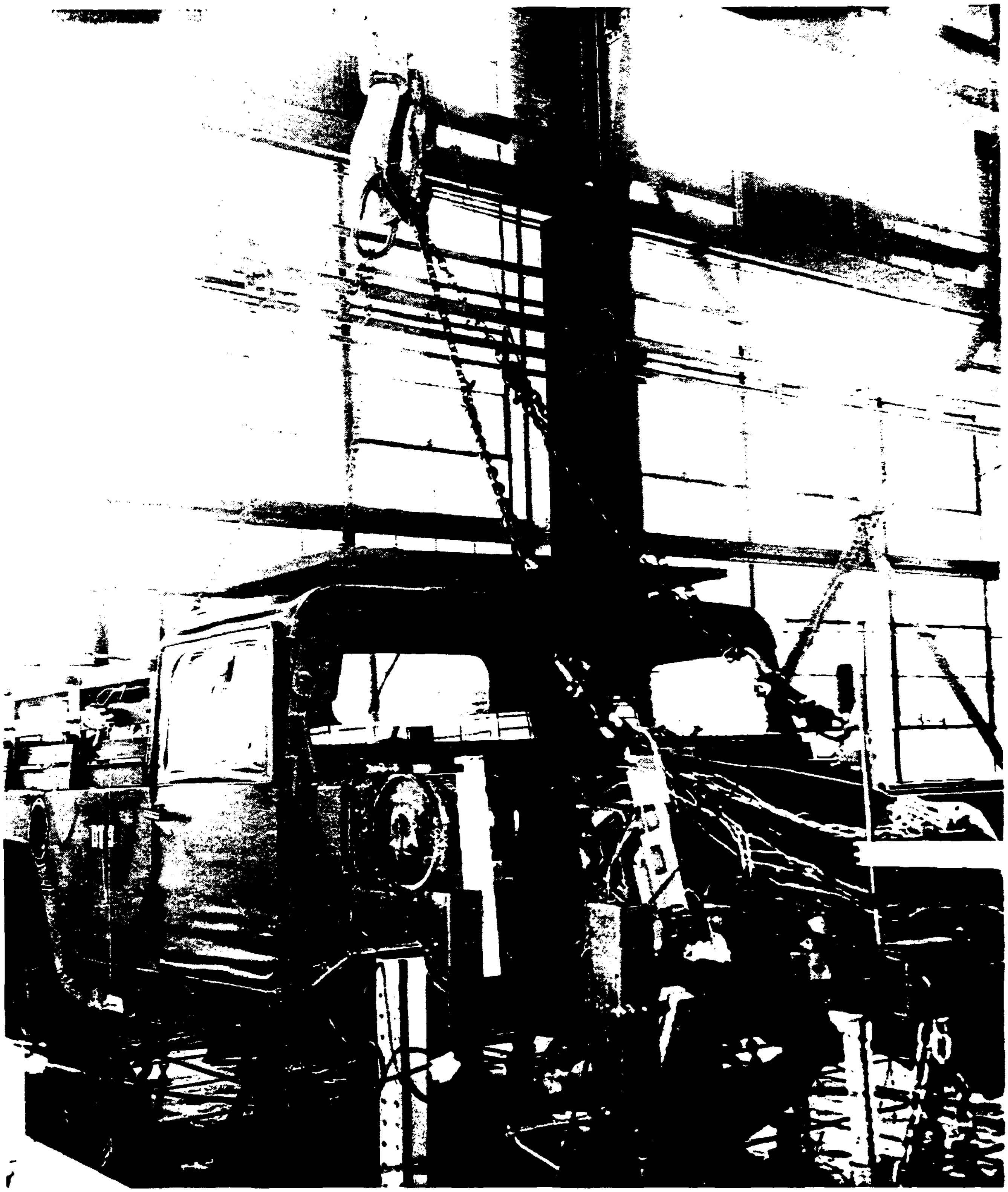

Figure 3. Load is applied to the provisions via an overhead crane.

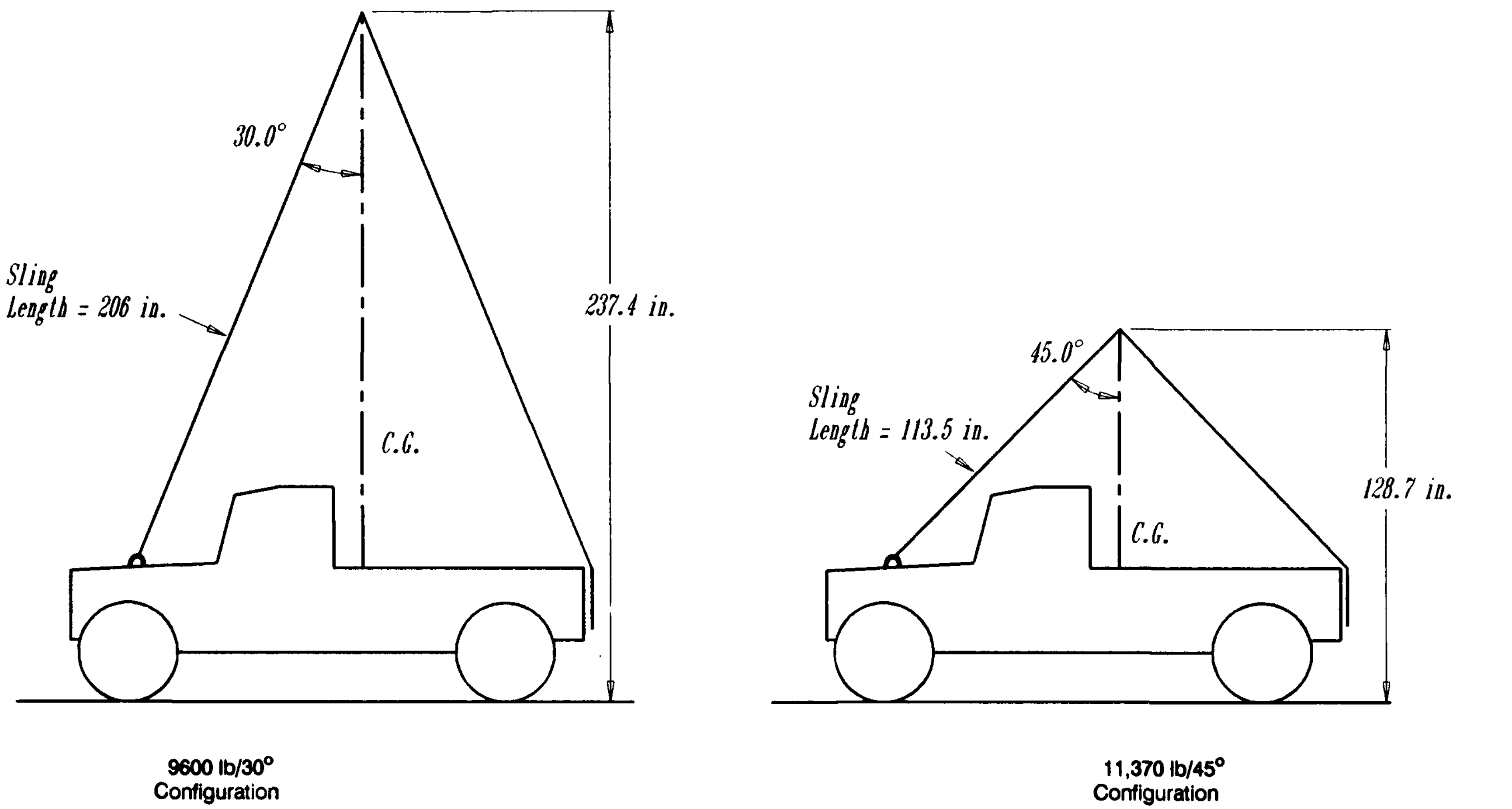

Figure 4. Load configurations relative to the vehicle.

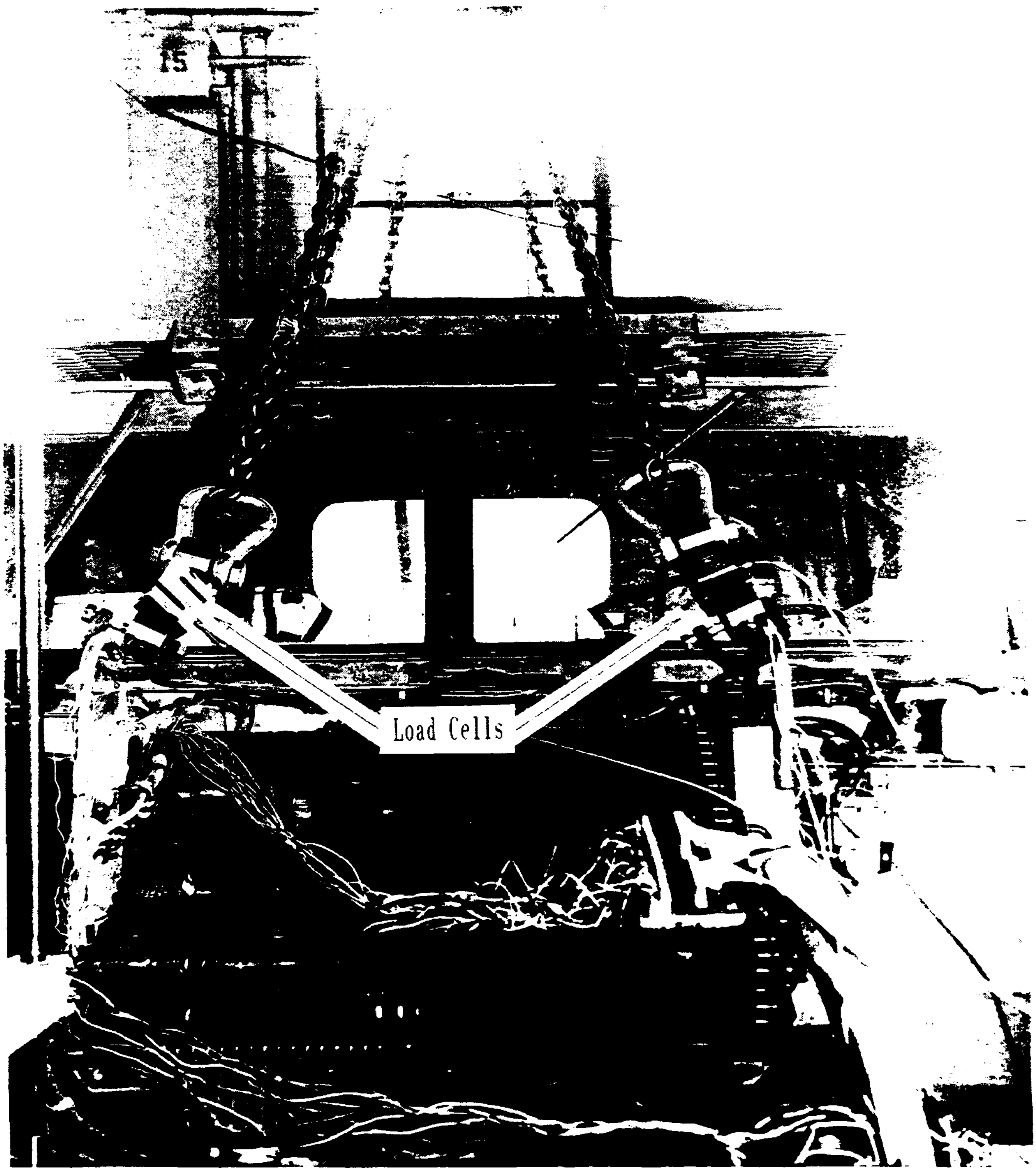

Figure 5. The load was monitored with the use of in-line load cells.

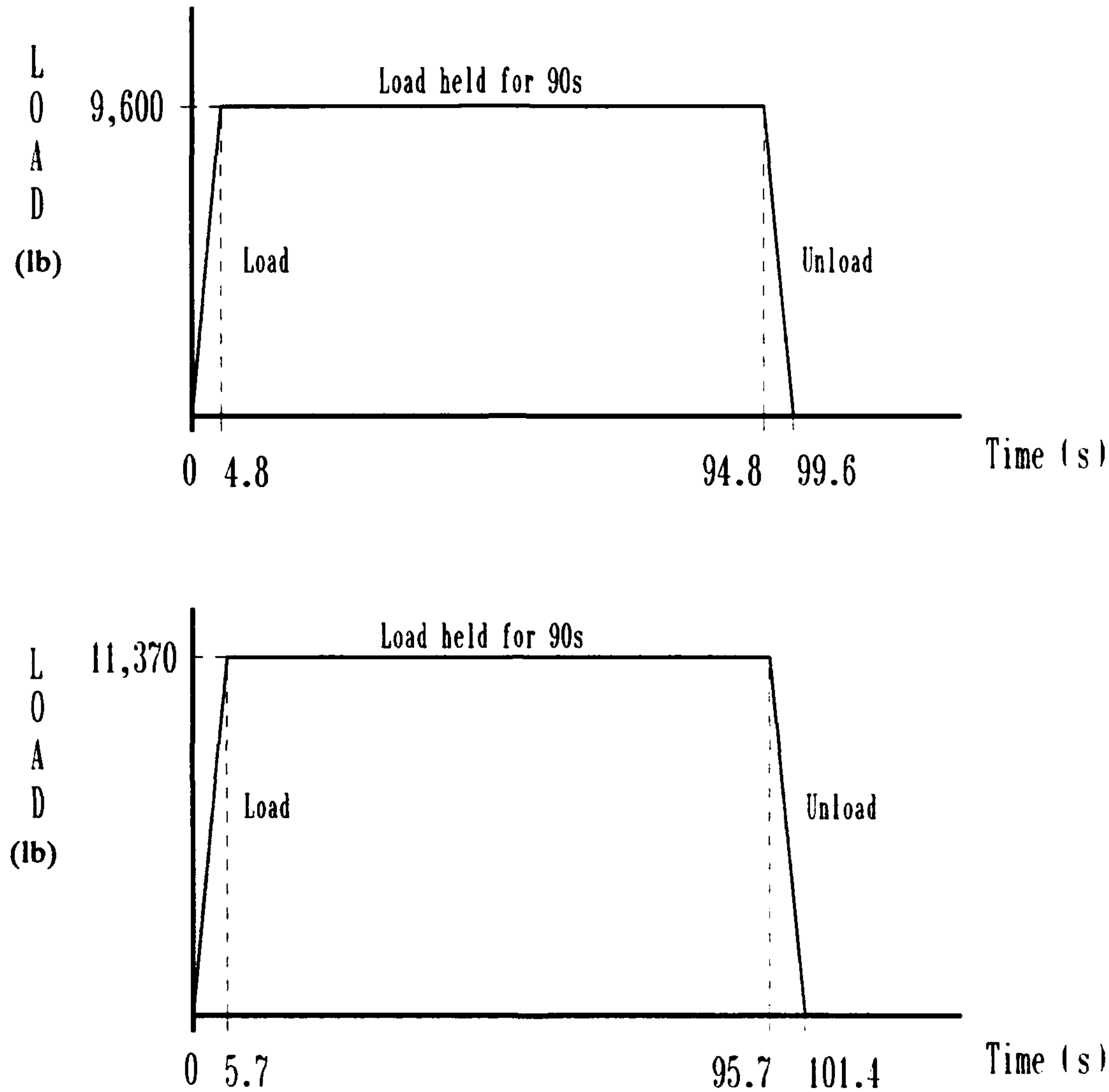

Figure 6. Load profiles for simulated air lift tests.

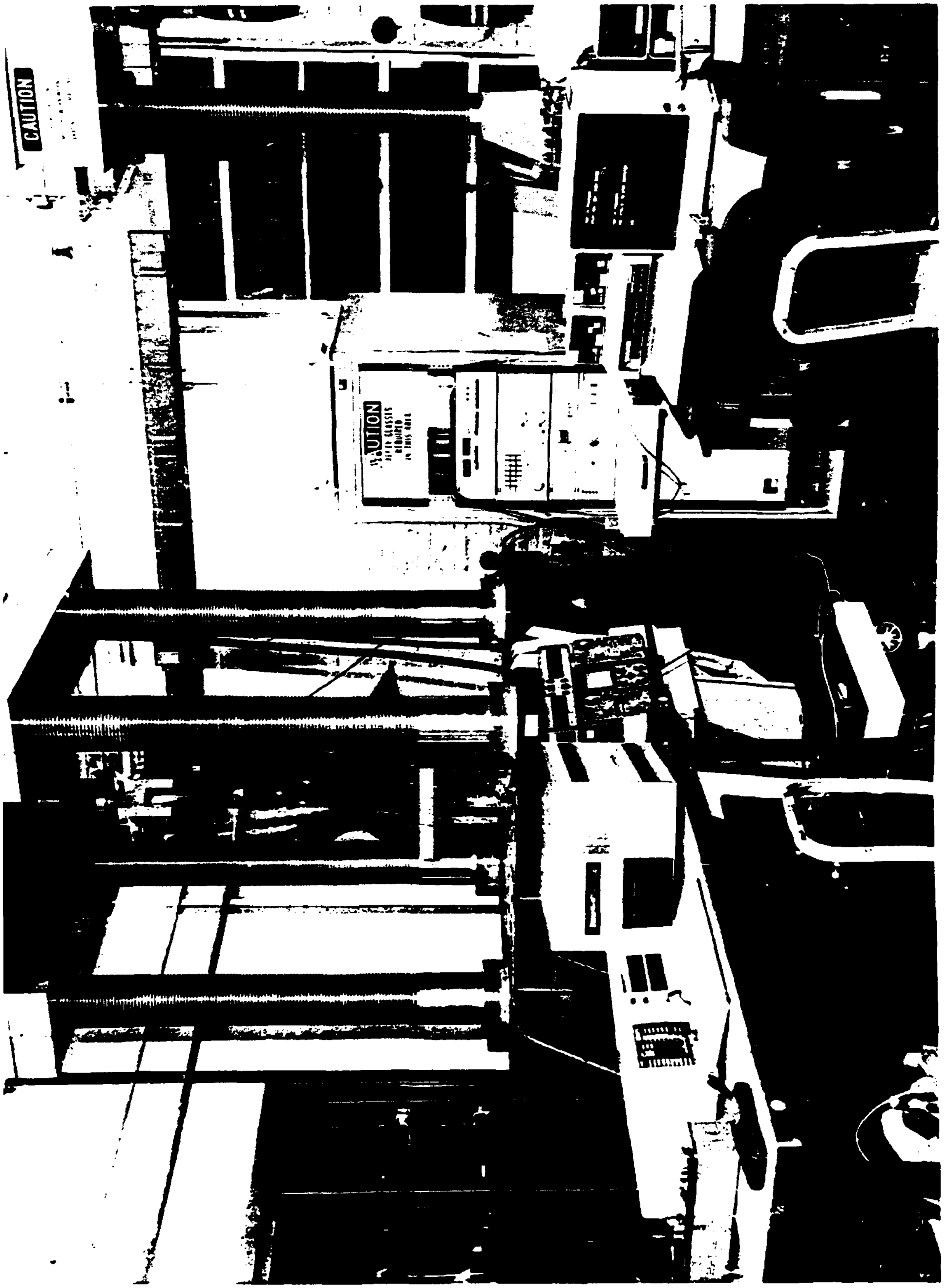

Figure 7. Ultimate pull test - machine and setup.

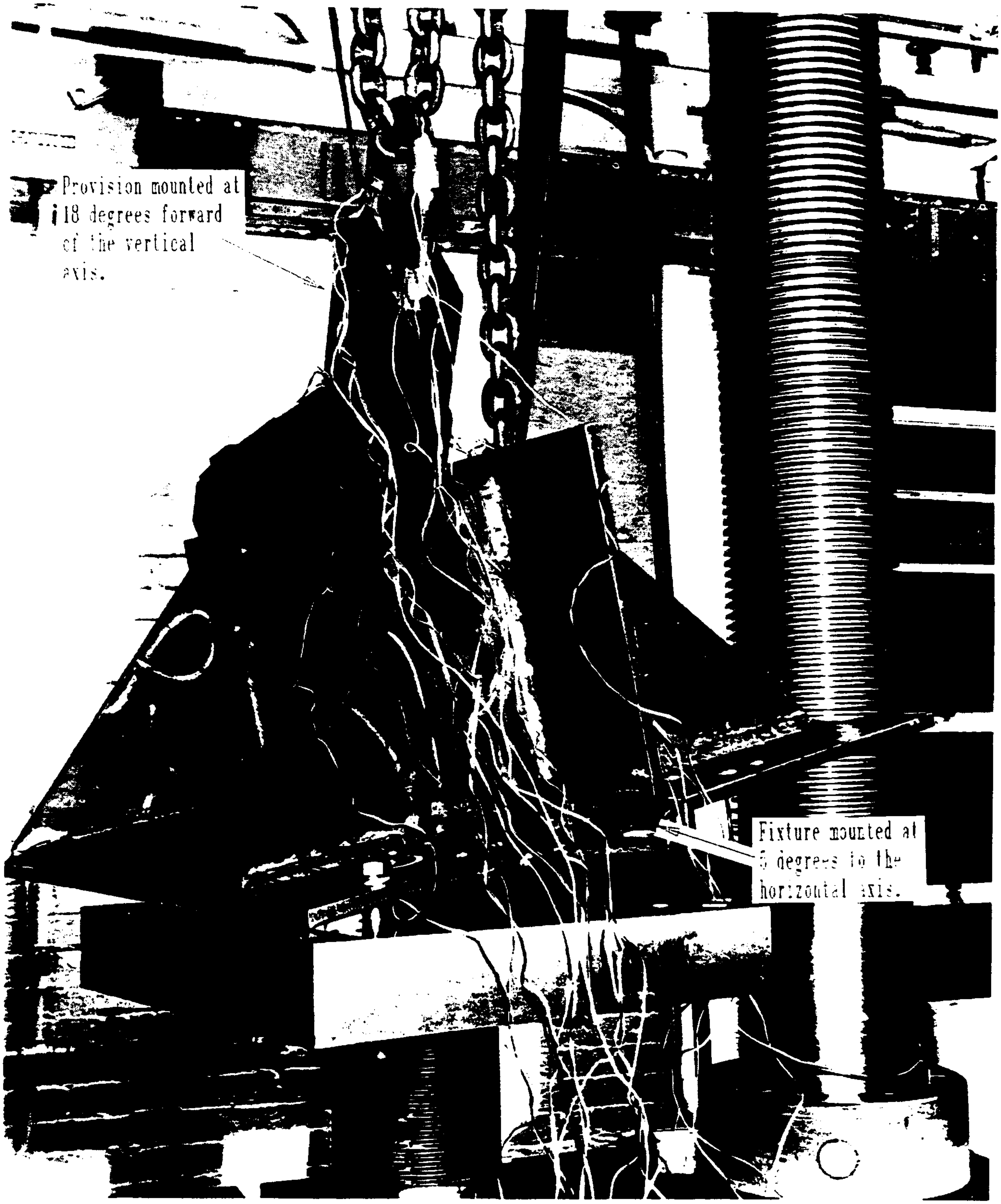

Figure 8. Fixture and provision installation for 9600 lb ultimate pull test.

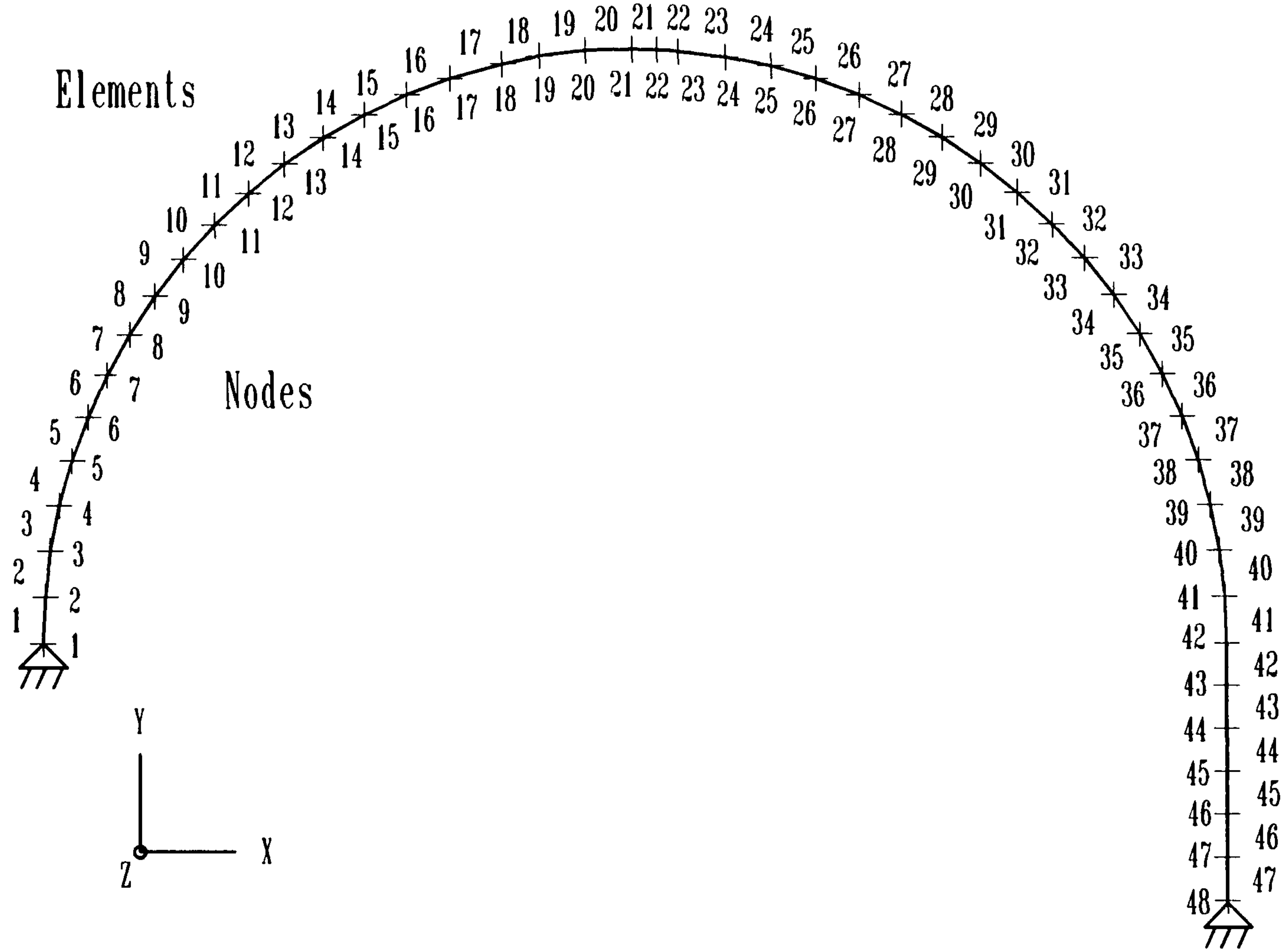

Figure 9. Finite element model of the hook.

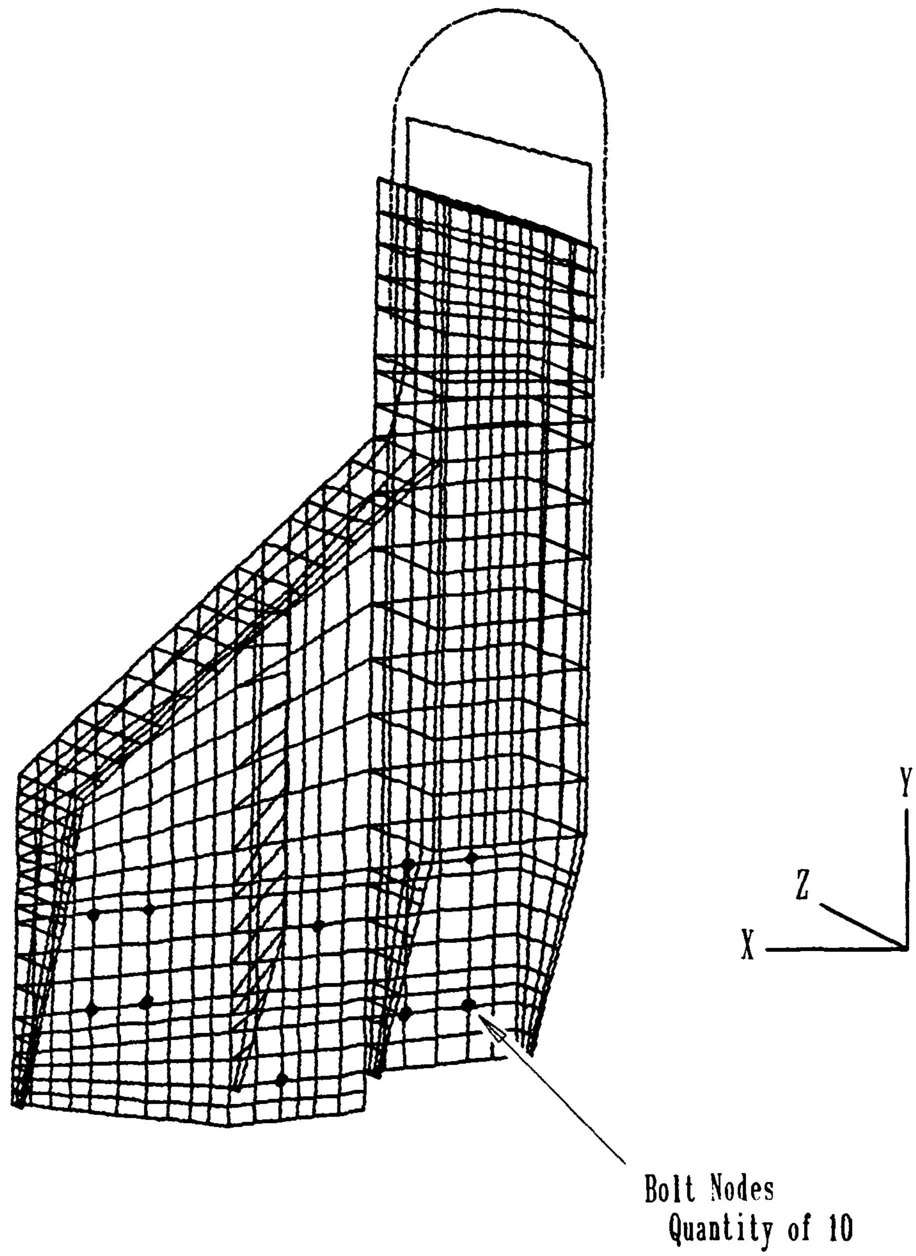

Figure 10. Finite element model of the provision bracket.

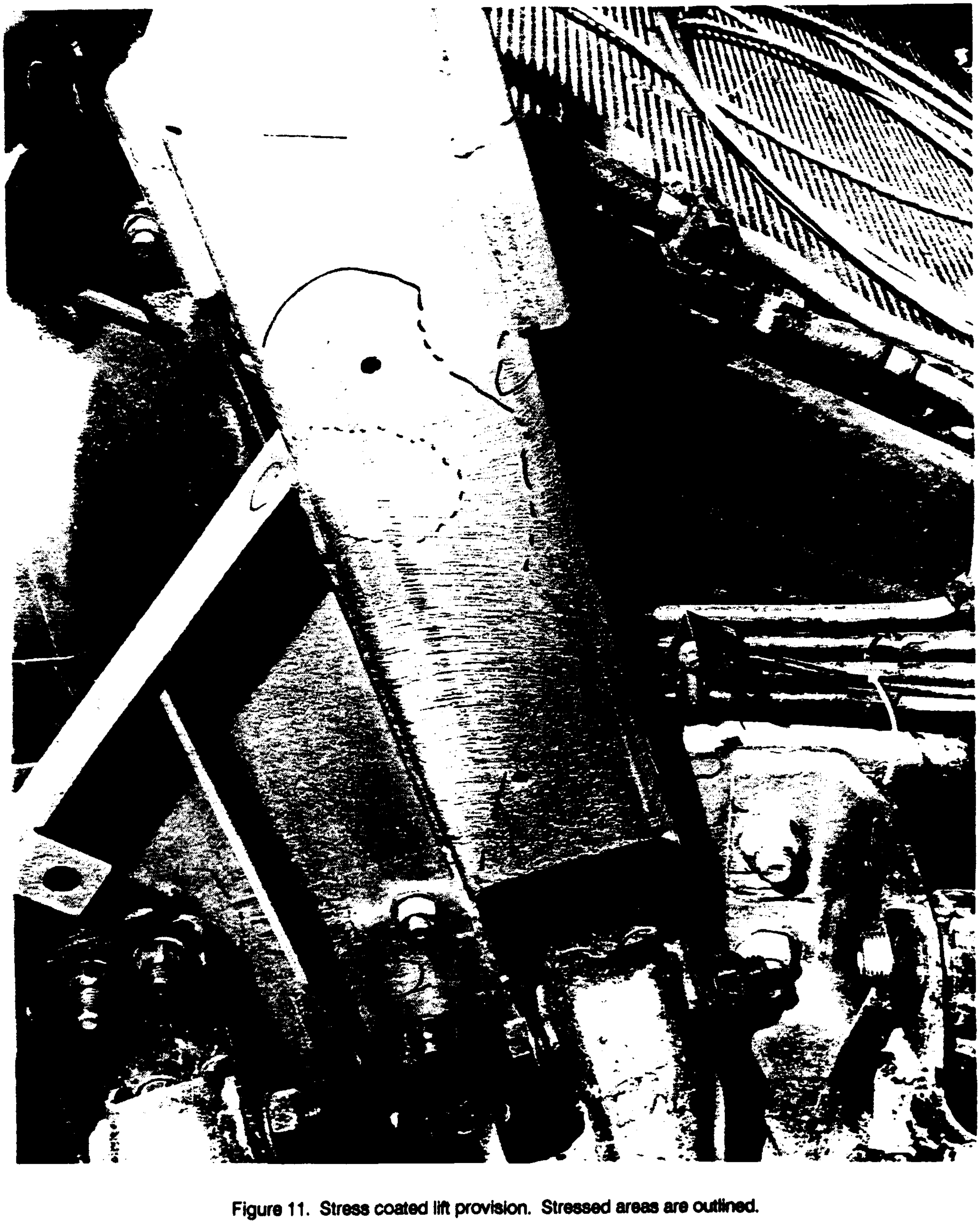

Figure 11. Stress coated lift provision. Stressed areas are outlined.

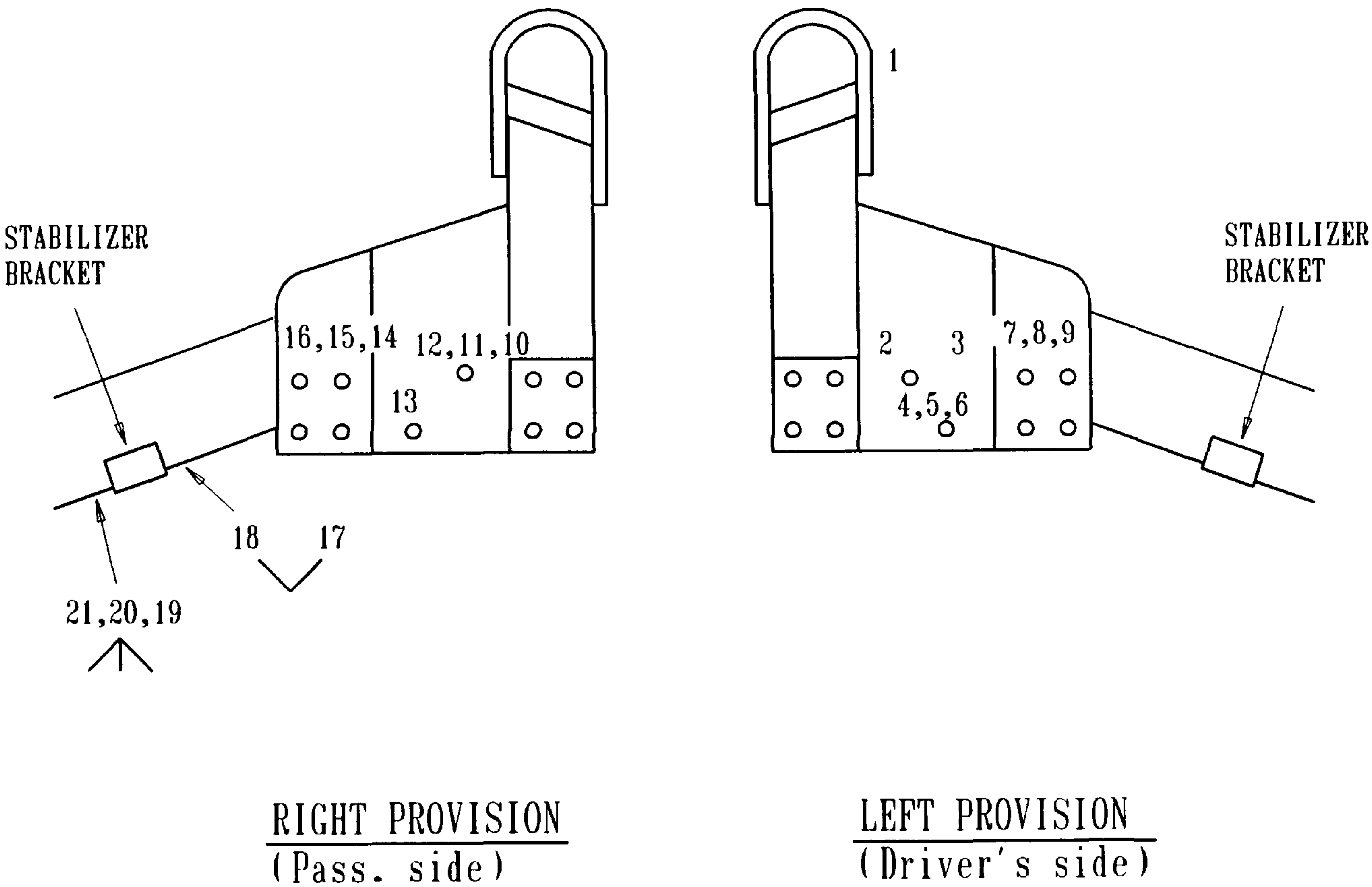

Figure 12. Strain gage map for the simulated air lift tests.

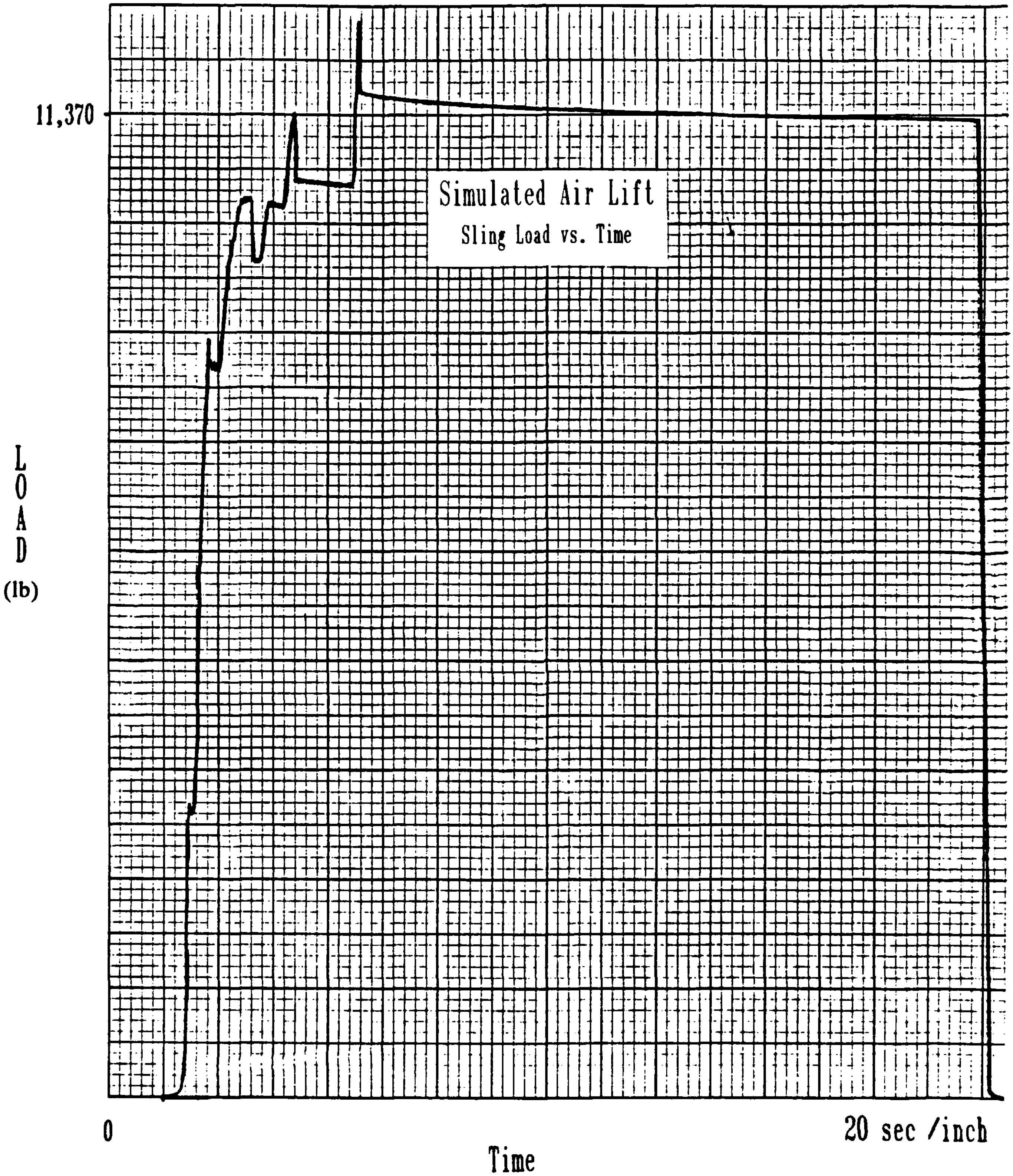

Figure 13. Plot of sling load versus time (11,370 lb configuration).

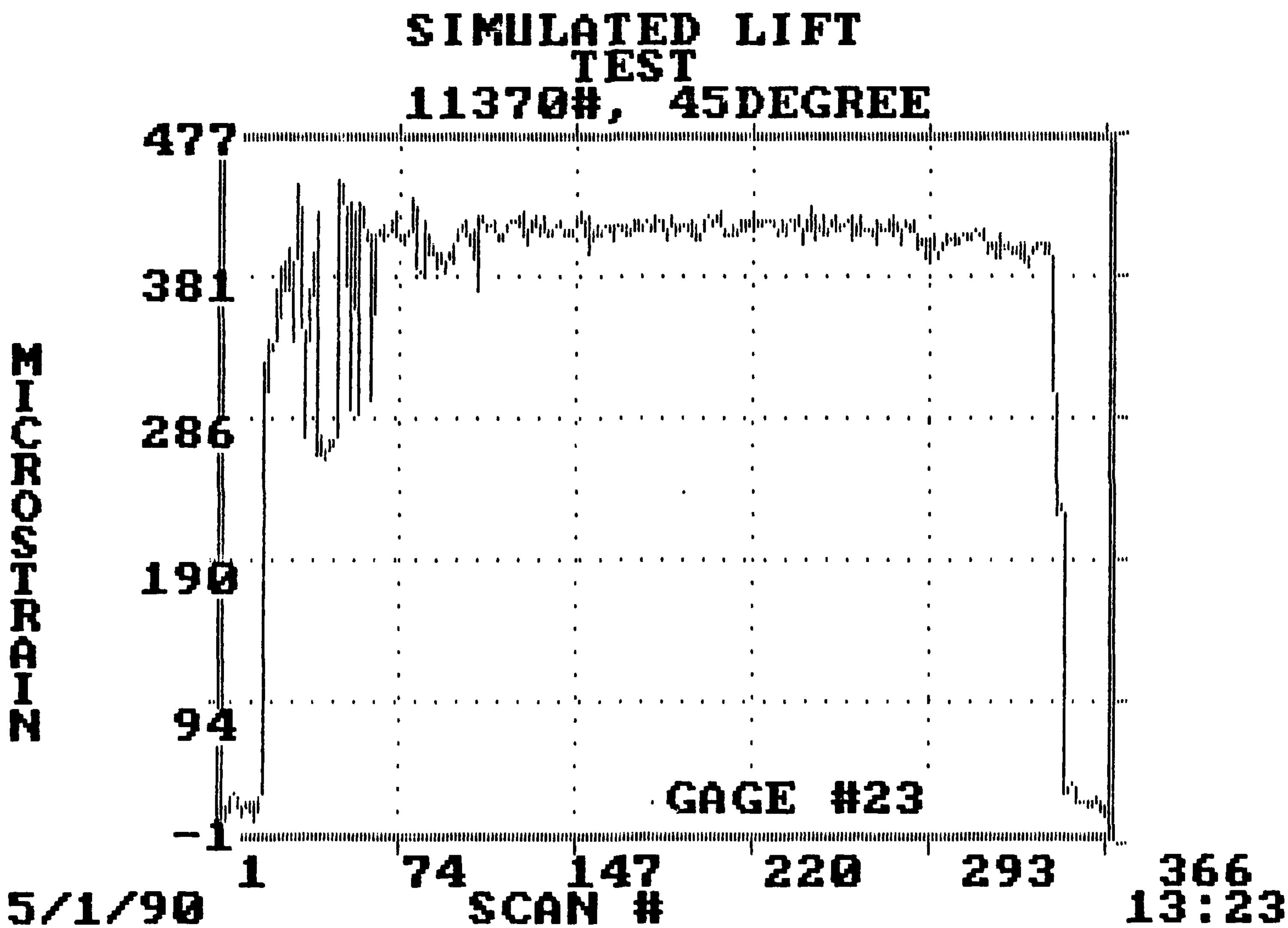

Figure 14. A typical strain versus scan plot.

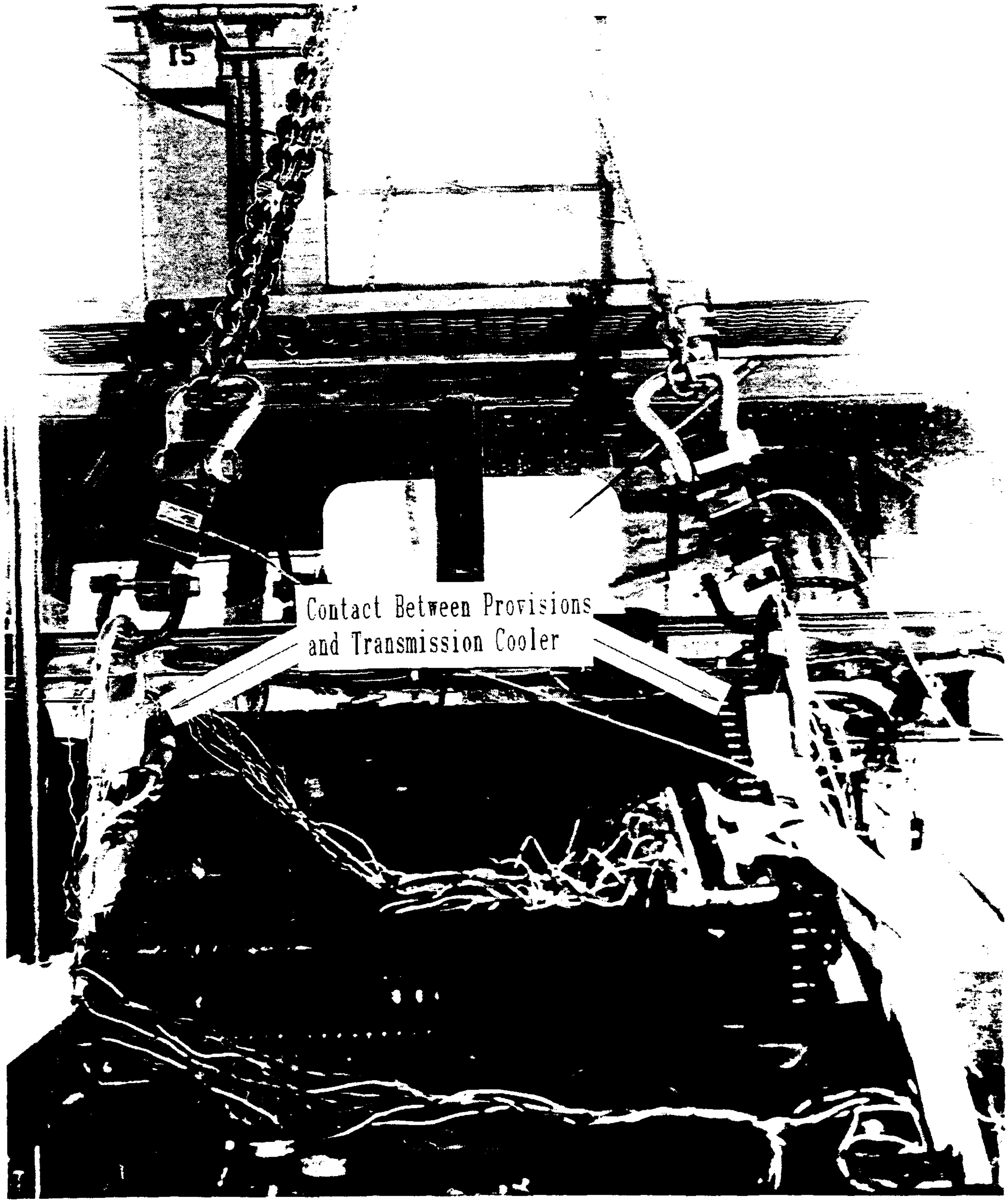

Figure 15. Provisions in contact with the transmission cooler.

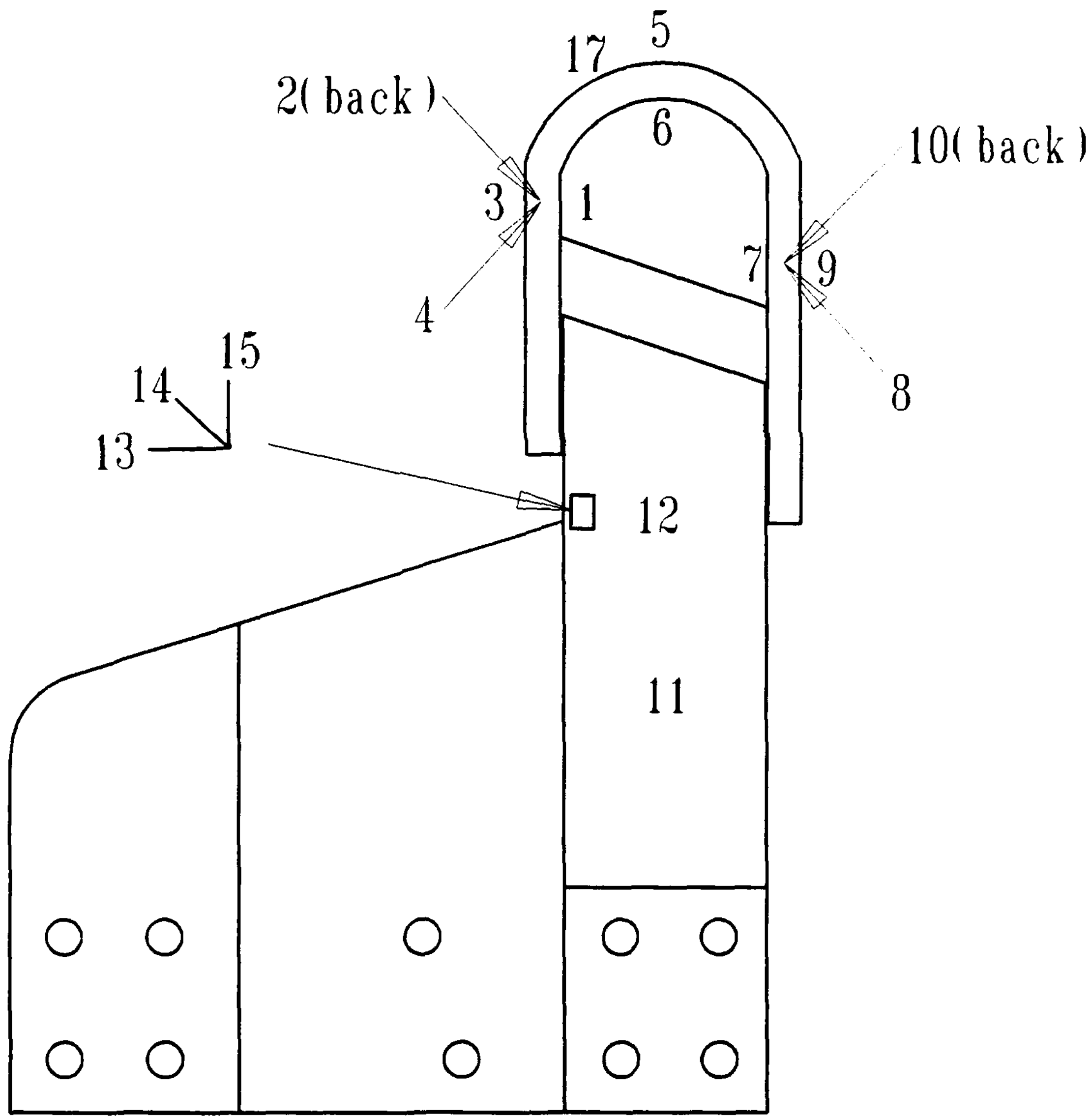

Figure 16. Strain gage map for ultimate pull and fatigue tests.

Figure 17. Crack locations (arrows) on provision A after 9600 lb ultimate pull test.

Figure 18. Crack locations (arrows) on provision B after 11,370 lb ultimate pull test.

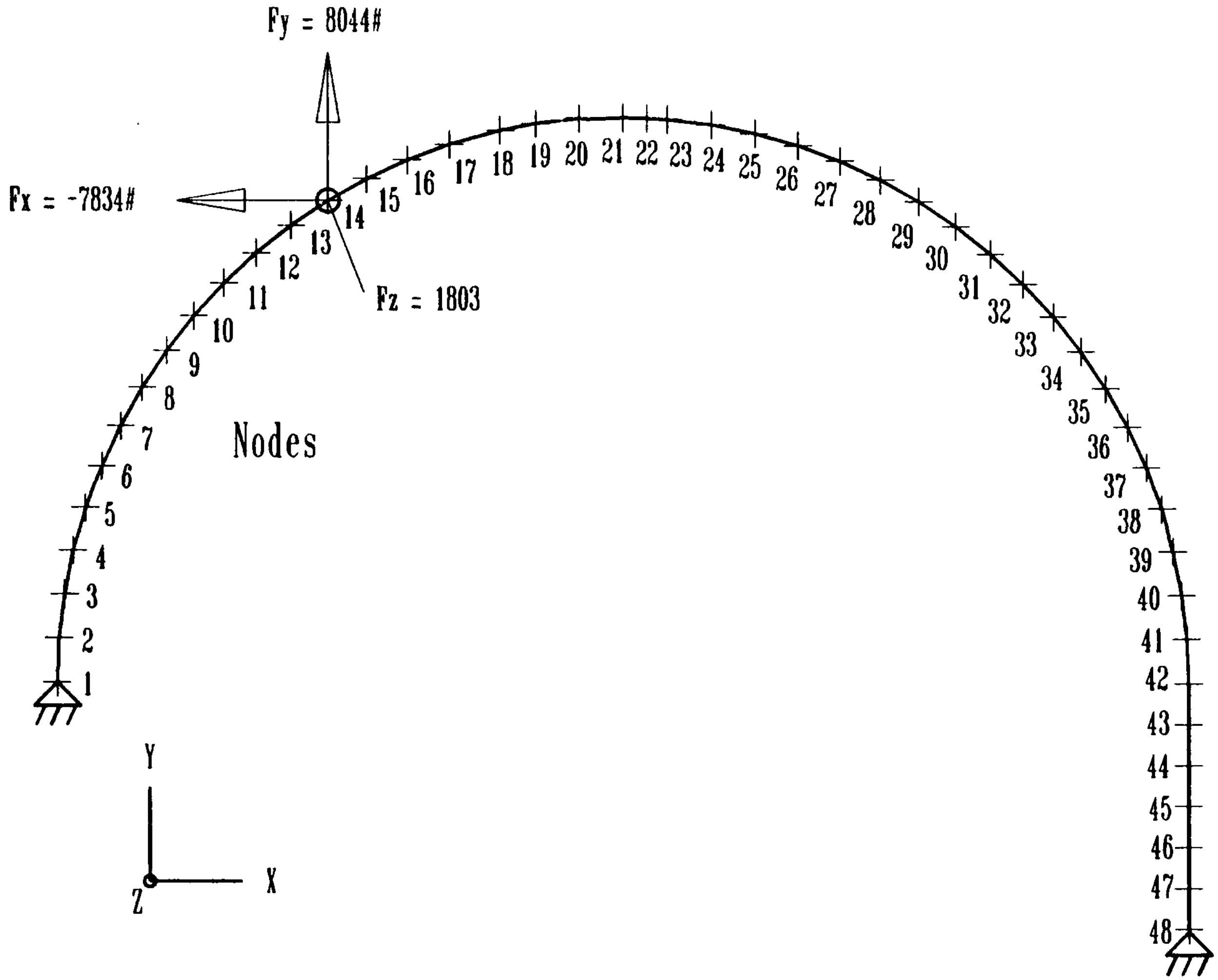

Figure 19. Hook model showing the 11,370 lb load components.

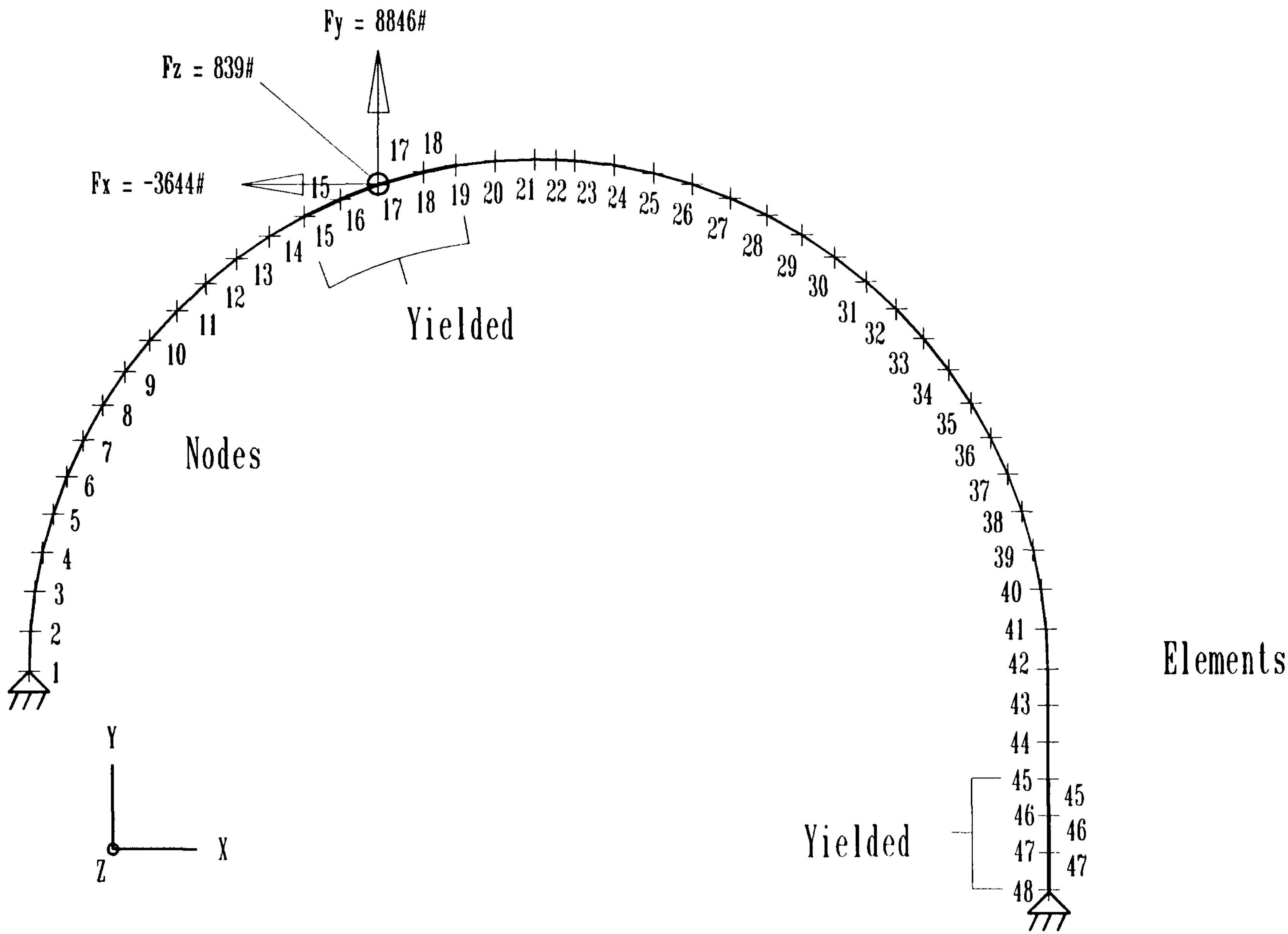

Figure 20. Yielded areas of the hook model (9600 lb configuration).

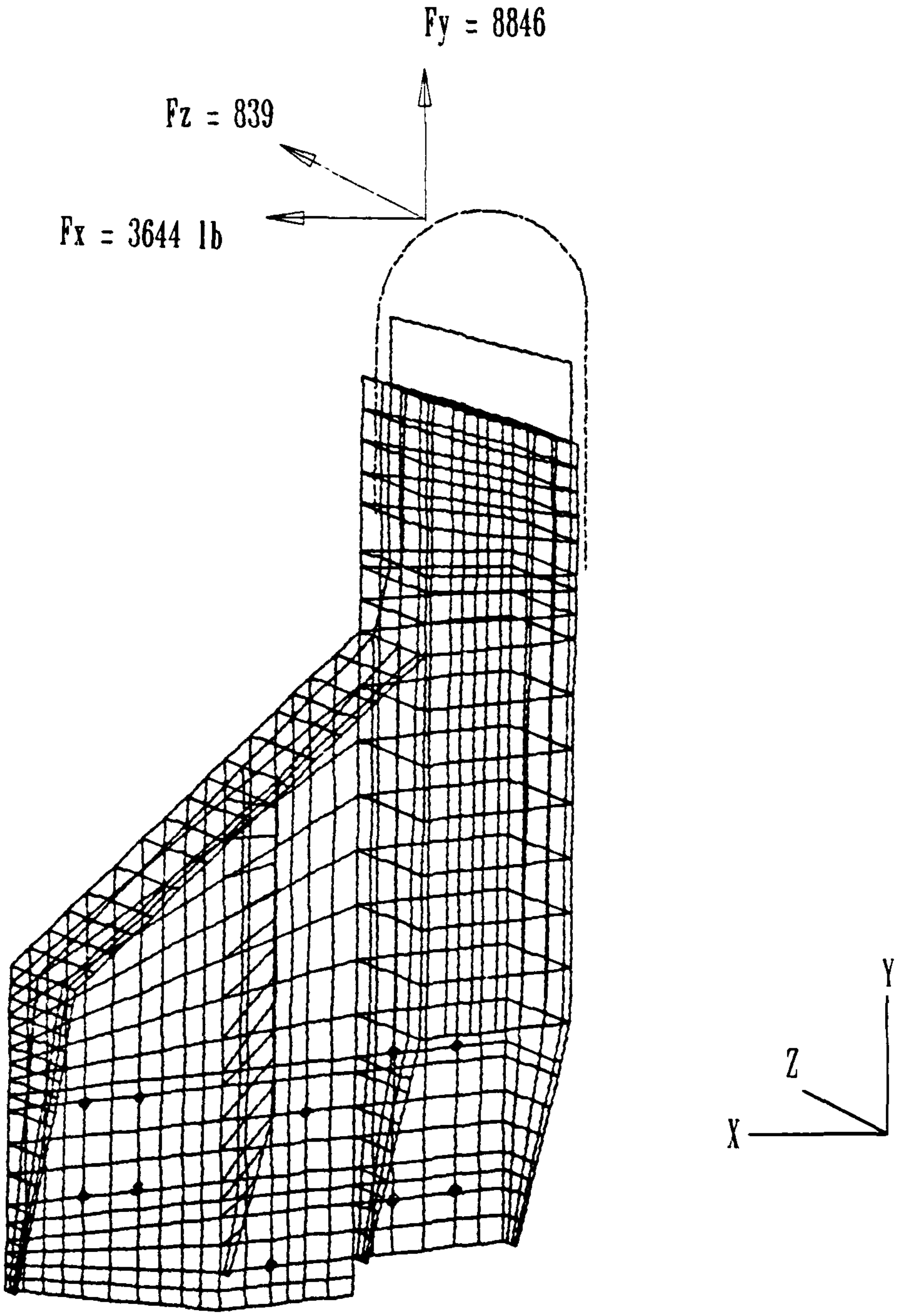

Figure 21. Lift provision model illustrating the 9600 lb load component vectors.

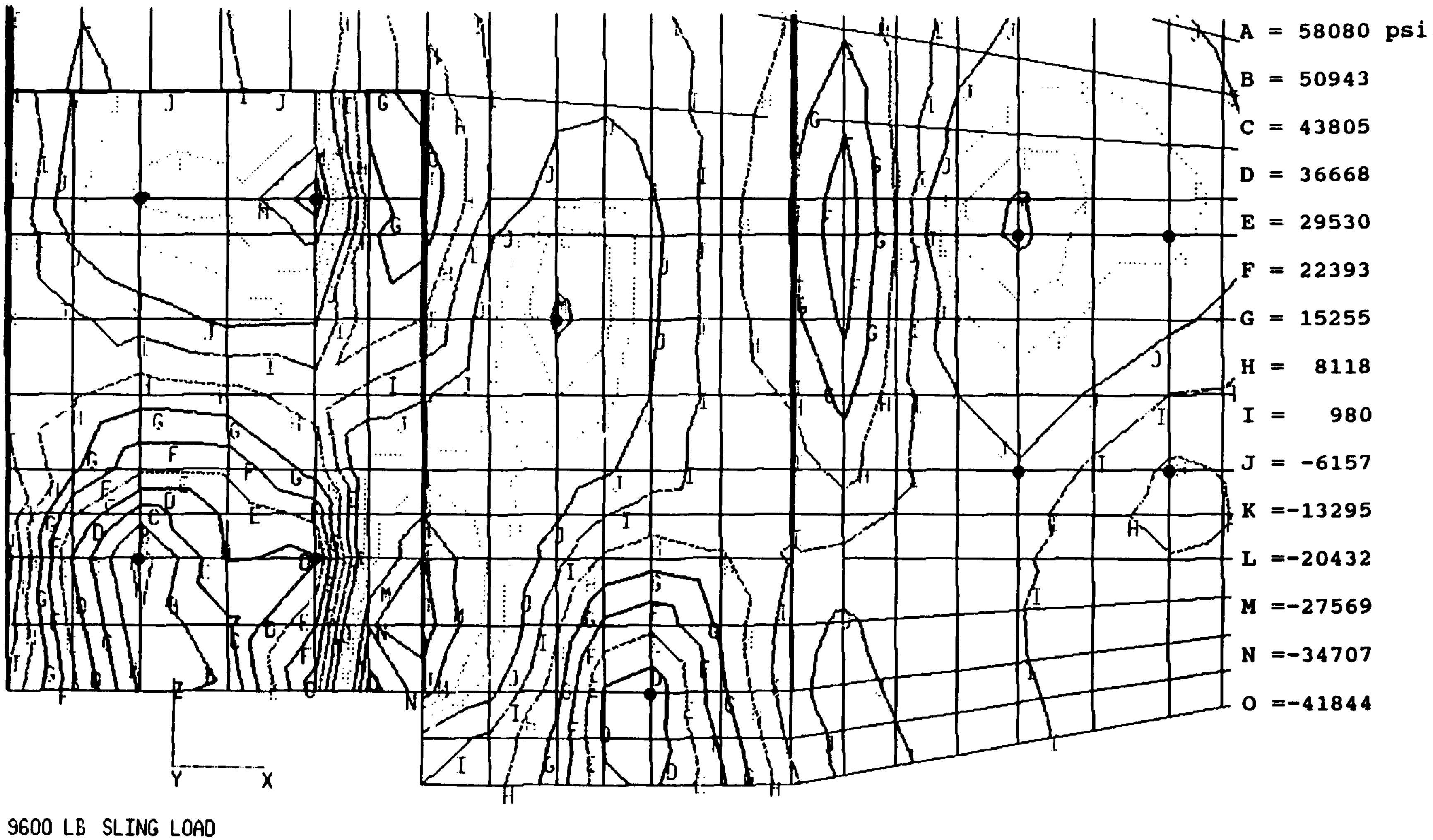

Figure 22. Stress contour plot of bolt node (solid corcles) areas from the 9600 lb analysis.

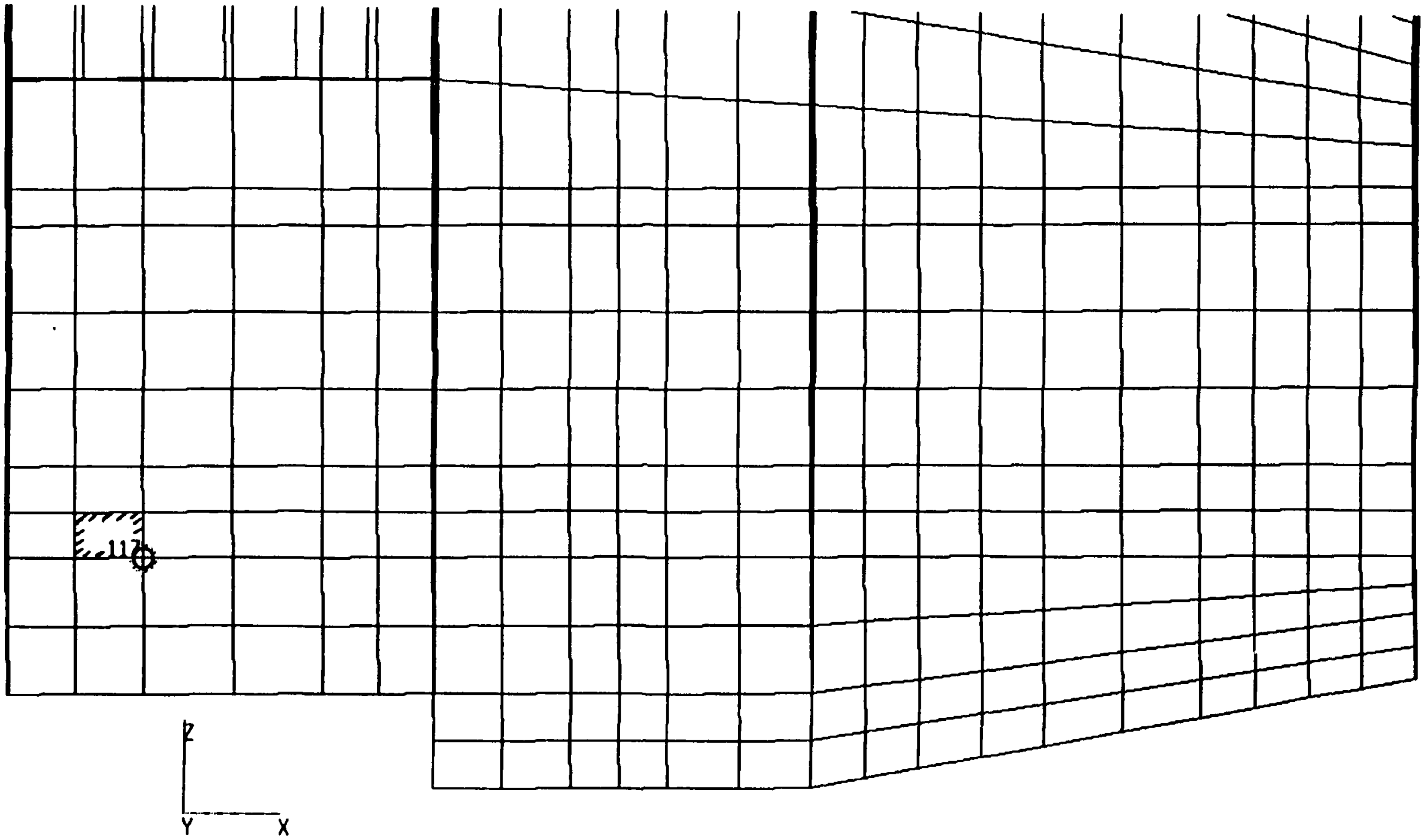

Figure 23. Element location that yielded at a bolt node during the 9600 lb analysis.

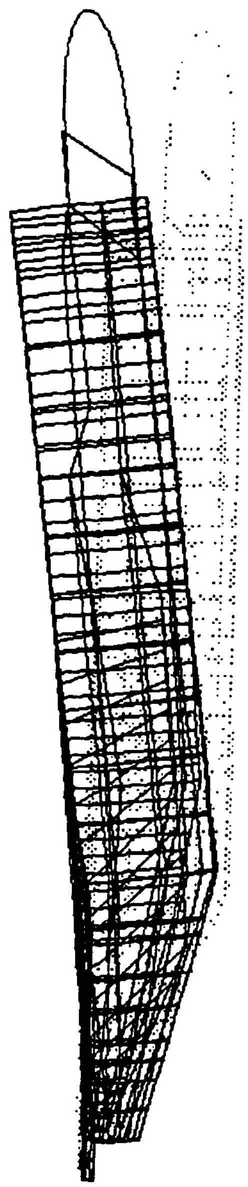

Figure 24. Illustration of the deformed provision model overlaying the undeformed mesh.

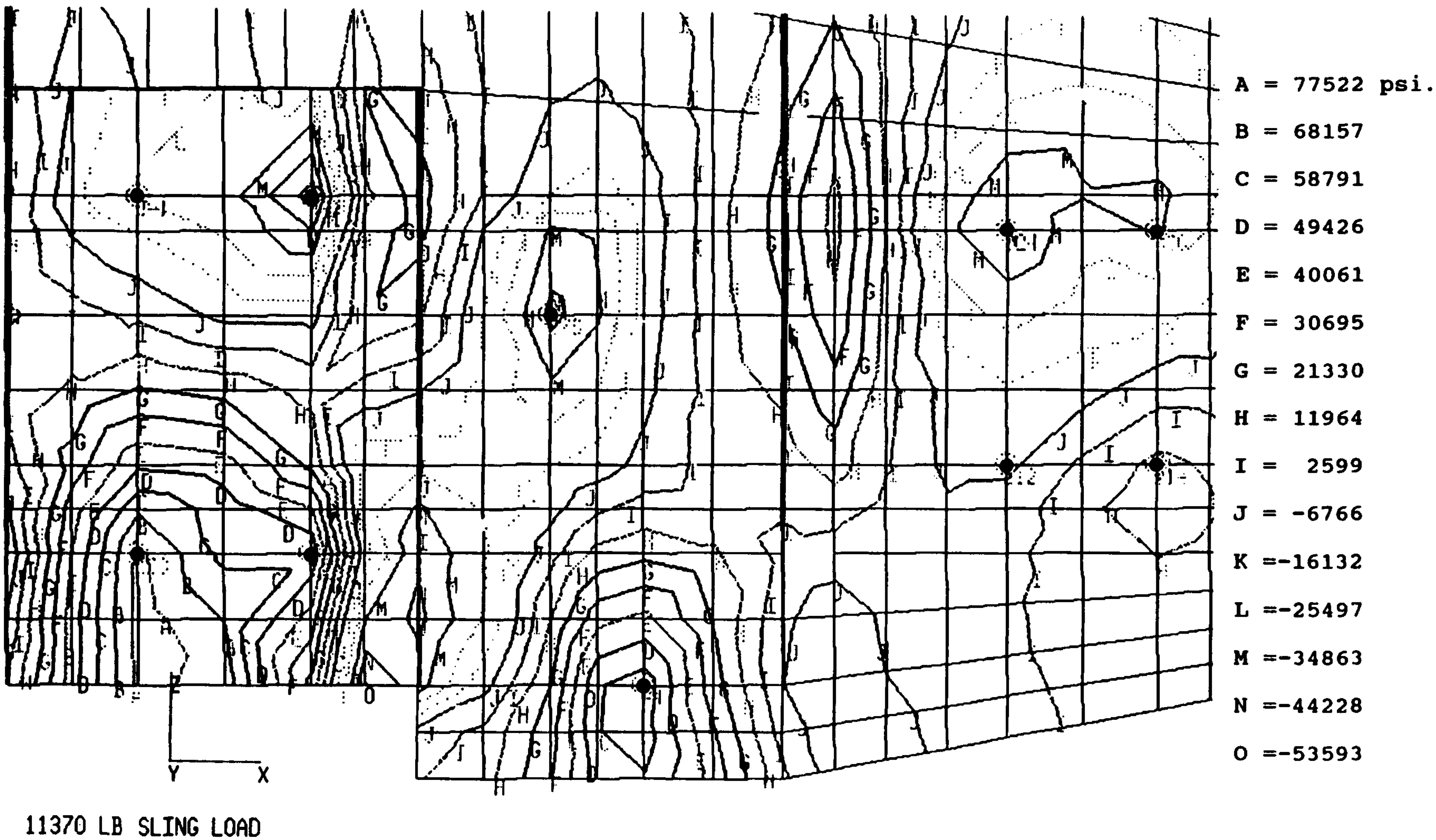

Figure 25. Stress contour plot of bolt node (solid circles) areas from the 11,370 lb analysis.

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Chistopher Cavallaro, Robert B. Dooley, Kristen D. Weight, and Paul V. Cavallaro

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